August 3, 1998

To the College of Engineering and Science:

This special project report entitled "Predicting the Performance of Belt Filter Presses using the Crown Press for Laboratory Simulation" and written by Todd Michael Graham is presented to the College of Engineering and Science of Clemson University. I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Engineering with a major in Environmental Engineering and Science.

David L. Freedman, Special Project Advisor

We have reviewed this special project report and recommend its acceptance:

C.P. Leslie Grady, Jr.

Tanju Karanfil

Accepted for the College of Engineering and Science:

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PREDICTING THE PERFORMANCE OF BELT FILTER PRESSES USING THE CROWN PRESS FOR LABORATORY SIMULATION

A Special Project Report

Presented to

the College of Engineering and Science of

Clemson University

In Partial Fulfillment

of the Requirements for the Degree

Master of Engineering

Environmental Engineering and Science

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by

Todd Michael Graham

August 1998

Advisor: Dr. David L. Freedman

ABSTRACT

Belt filter presses (BFPs) are among the most commonly used devices to dewater wastewater sludge. The concept used by a BFP to achieve dewatered cake solids is relatively simple; however, replicating this performance in the laboratory in order to predict the performance of a BFP with reasonable reliability has proven to be a challenge. The Crown Press is one tool that has been shown to replicate the performance of anaerobically digested sludge on a BFP.

This study used the Crown Press to replicate and predict the performance of waste activated sludge (WAS) from the Mauldin Road wastewater treatment plant on BFPs. Several operational variables, including belt speed, belt tension, polymer type, and polymer dose, were changed on the Crown Press to predict how the changes on the BFP would affect performance. Two polymers were chosen to be tested on the BFPs at Mauldin Road based on Crown Press predictions. The first polymer performed the same as the plant's current polymer in the lab, and the second performed better (achieved higher final cake solids) than the current polymer. These predictions were borne out in the BFP tests, showing that the Crown Press predictions were accurate. The Crown Press predictions were also compared to the predictions made by the capillary suction time (CST) and specific resistance to filtration (SRF) tests. The Crown Press provided more information regarding the affect of polymer type and dose on cake solids than either CST or SRF. The Crown Press was shown to be a viable tool to assess potential changes in BFP performance with WAS when operational variables change.

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LIST OF ABBREVIATIONS

BFP	Belt Filter Press
CPGR	Crown Press Gauge Reading
CST	Capillary Suction Time
DAF	Dissolved Air Flotation
ES	Environmental Specialties
IF	Industrial Fabrics
LCS	Lab Conditioned Sludge
PCS	Plant Conditioned Sludge
SCD	Streaming Current Detector
SRF	Specific Resistance to Filtration
TSS	Total Suspended Solids
WAS	Waste Activated Sludge
WCRSA	Western Carolina Regional Sewer Authority
WEF	Water Environment Federation
WWTP	Wastewater Treatment Plant
WZS	Wedge Zone Simulator

CHAPTER 1

INTRODUCTION

Dewatering of sludge that results from any waste treatment process is done for many reasons and is accomplished via a number of techniques. Sludge, as defined by the Water Environment Federation (WEF), is generally used to describe solids before they have been treated to meet recycling criteria, which typically occurs at the outlet of the stabilization process. Biosolids, on the other hand, is used to refer to the solids after applicable beneficial recycling criteria have been achieved. This typically requires digestion, alkaline stabilization, or some type of drying (WEF, 1996). In this project, sludge is the correct terminology for the solids used. Some of the reasons for removing moisture from sludge include increased energy for incineration, ease of handling and regulatory requirements (Metcalf & Eddy, Inc., 1991). Typically, though, the driving forces behind most dewatering processes are the costs for hauling sludge to the ultimate disposal site and the costs for landfilling. At the end of most treatment processes, the concentrated sludge is still a fairly dilute slurry of 1-8% solids by weight. This means that 92-99% of the weight is water. At a density of 1 kg/L, the water portion of sludge is an expensive component to transport and dispose of. By removing as much moisture as possible prior to disposal, the mass and volume of sludge exiting a plant are minimized.

There are many techniques used to dewater sludge. Some rely on non-mechanical processes such as evaporation and percolation with lagoons and sand drying beds. Others use mechanical means to remove moisture more quickly. Vacuum filters, centrifuges, belt filter presses (BFPs), and recessed plate filter presses are the main mechanical

dewatering processes used. Each alternative has multiple advantages and disadvantages as presented by Metcalf & Eddy, Inc. (1991) that must be considered when choosing the appropriate dewatering device for a treatment process. The BFP is one of the most commonly used devices for dewatering municipal wastewater sludges and is the focus of this study.

The popularity of the BFP has increased during the past 15-20 years for treatment plants of all sizes, yet accepted procedures for evaluating their performance are still very limited. There are two basic options for investigating the usefulness of the belt filter press with a given sludge. The first option is to bring a full-scale BFP to the treatment plant for several weeks or months of testing. This will allow operators to experiment with changes in polymer type, polymer dose, belt type, belt speed and belt tension in order to find the most effective combination for successful dewatering. This is currently the most reliable method for evaluation but is the most expensive due to machine rental rates ranging from $1,500-$3,000 per month (Galla, 1996).

The second option that can be used to evaluate the use of a BFP is to perform laboratory tests with bench-scale devices which simulate BFP operation. These include the piston press, the wedge zone simulator, and the Crown Press, which are described in detail in Chapters 2 and 3. There are also several general tests which are accepted means to assess sludge dewaterability, including specific resistance to filtration (SRF), capillary suction time (CST), and gravity drainage tests. While the general tests may be helpful in screening polymers, it is questionable how well they predict what will happen on a BFP.

Although none of the laboratory tools mimic the full scale operation of a BFP perfectly, finding a reliable correlation between a laboratory test and actual BFP

performance would be extremely beneficial. This would not only allow treatment plants considering the purchase of a dewatering device the chance to predict performance of a BFP with their sludge, but would also provide a cost-saving tool to polymer manufacturers, BFP distributors, and belt fabric suppliers. In addition, treatment plants already using BFPs would be able to test parameter changes without interrupting operation.

Galla et al. (1996) tested the ability of the Crown Press to simulate BFP performance with anaerobically digested primary plus secondary sludge. The Crown Press was used to successfully predict a conservative BFP operating region, which is described in section 4.3. The Crown Press was also used to evaluate and select the optimum belt type and to rule out polymer selection as the cause of poor dewaterability at a wastewater treatment plant (WWTP) in Urbana, Illinois.

The goal of this research project was to compare the effectiveness of the Crown Press with other general laboratory tests for predicting the performance of BFPs in response to changes in polymer type, polymer dose, belt type, and belt speed and tension. The predictions were tested on the BFPs at the Western Carolina Regional Sewer Authority (WCRSA) Mauldin Road WWTP in Greenville, South Carolina.

The objectives of this project were:

1. To determine if the Crown Press procedure developed by Galla et al. (1996) can also be used to predict dewatering of undigested waste activated sludge (WAS);
2. To compare these predictions with CST and SRF measurements;
3. To measure solids capture efficiency with the Crown Press;

4. To find a polymer that will give better performance than the one currently being used at the Mauldin Road facility;
5. To test the better polymer on the BFP at the Mauldin Road facility; and
6. To recommend operational changes to improve performance of the BFPs at the Mauldin Road facility.

The methods developed by Galla et al. (1996) for the Crown Press, which produced results with anaerobically digested sludge that correlated well to BFP dewatering, have been found to be applicable to undigested WAS. The Crown Press accurately replicated the performance of the BFP using plant conditioned sludge (PCS) from the Mauldin Road WWTP. Evaluation of different polymers on the Crown Press showed that increasing doses improved the solids content of the final cake, although with diminishing returns. CST and SRF tests did not predict this effect of polymer dose on final cake solids. The results of these evaluations were used to predict the performance of the polymers on the BFPs at the Mauldin Road WWTP. The plant tests with two of the polymers verified the predictions made with the Crown Press.

CHAPTER 2

BACKGROUND

There are several major topics relevant to this project which are presented here for background information. The first topic is the background and general operating information on the BFP as it relates to the wastewater treatment industry. Next, is a review of the role water plays in sludge particles. Then sludge conditioning as it relates to BFP dewatering is discussed. The fourth topic presented is a comparison of laboratory methods for predicting dewaterability.

2.1 Belt Filter Press

Use of the BFP for removal of water from sludge is a widely used technology that dates back to the early 1970s in the United States. The design concept of a BFP is very simple. The BFP uses a combination of gravity drainage and mechanically applied pressure to dewater chemically conditioned sludge. Pressure is applied as the sludge is squeezed between two pieces of porous belt fabric and passed over a sequence of rollers. The belt material is typically made of polyester and comes in various weaves and thread counts. Haworth (1973) discussed one of the early BFPs, called a filterbelt press, which was originally introduced in Germany in the early 1960's. This press, shown in Figure 2.1, had three distinct regions of dewatering: a drainage zone, a press zone, and a shear zone. The top belt was made of an impervious reinforced rubber, and the bottom belt was an open mesh of woven steel and polyester. Based on the diagrams, the shear zone was very limited due to the small wrap angles on the end rollers. In his study, a mobile

filterbelt press was used at numerous Sewage Works throughout Britain testing various types of sludges, including raw primary, "surplus" activated, and cold digested. Cake solids ranging from 12.6% to 32.6% were achieved with this device during the trials.

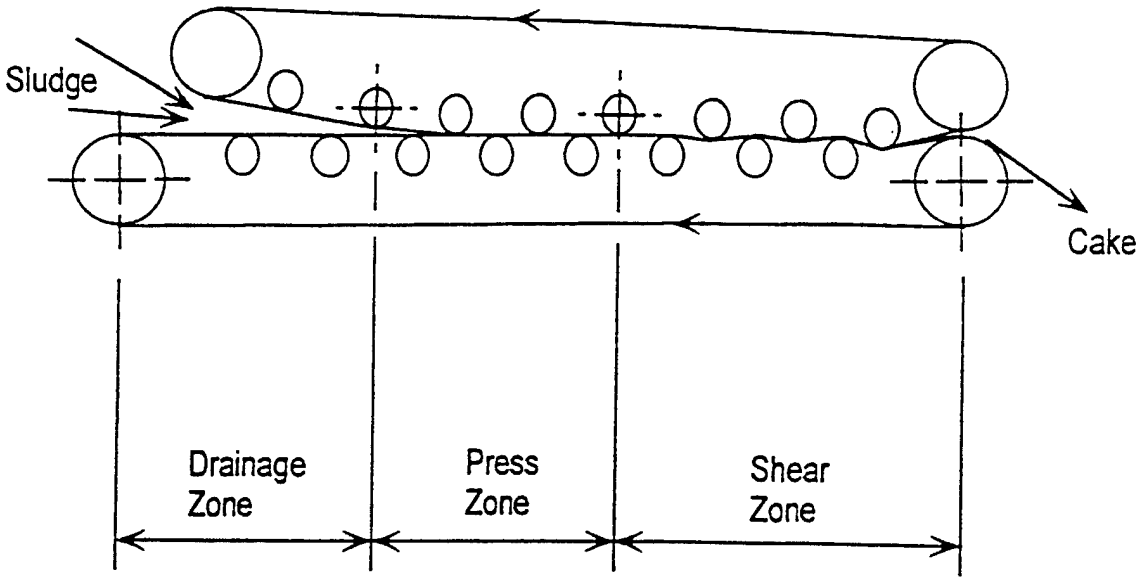


Figure 2.1 The Filterbelt Press (Haworth, 1973).

The modern BFP, as shown in Figure 2.2, has undergone dramatic changes since its introduction with the device shown in Figure 2.1. The photograph in Figure 2.2 is of a press manufactured by Eimco Inc., which is currently being used at the WCRSA Mauldin Road WWTP. These changes include the number of rollers in the shear zone, the wrap angle of the belt in the shear zone, and a modified gravity drainage zone. The gravity drainage zone incorporates agitation and plowing of the sludge with devices called chicanes to allow the release of free water from the conditioned sludge through the belt fabric. The chicanes, or plows shown in Figure 2.3, are typically rectangular pieces of plastic arranged in multiple rows along the length of the gravity drainage zone. The

plows sit on the surface of the belt and turn the sludge as it passes the rows of plows. The plows form the conditioned sludge into multiple rows which fall onto the bottom belt and enter the wedge zone.

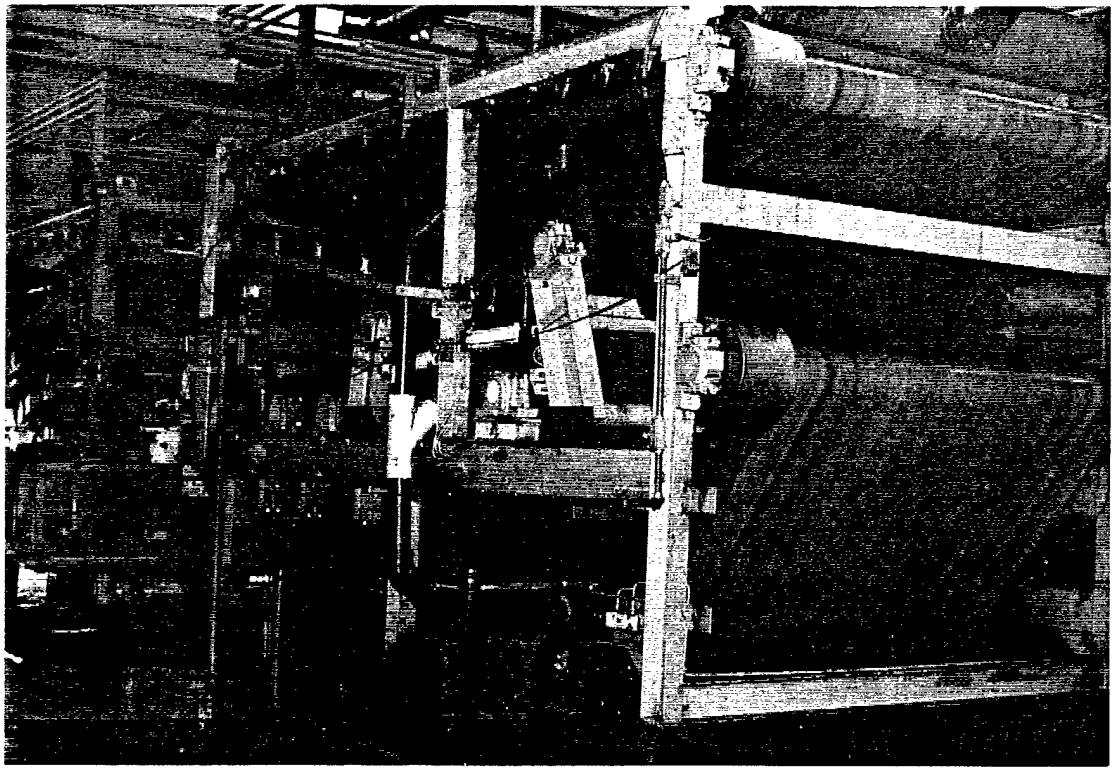


Figure 2.2 Photograph of a Belt Filter Press used at the Mauldin Road facility manufactured by Eimco, Inc.

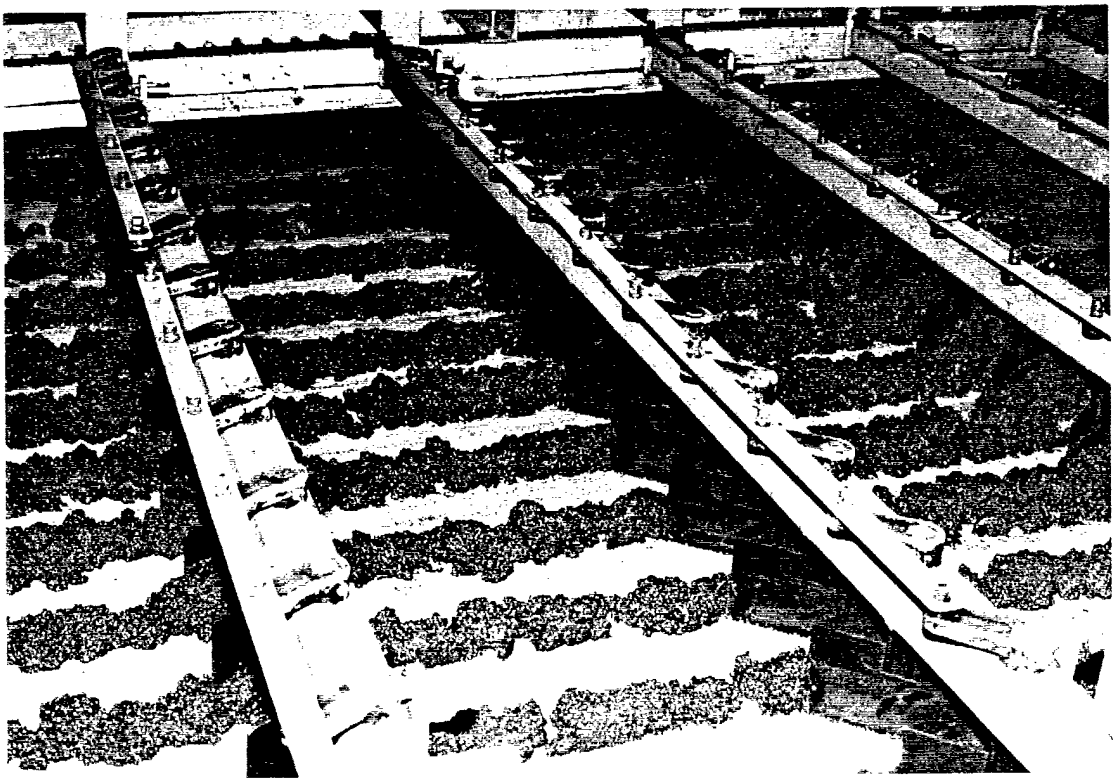


Figure 2.3 Photograph of the plows used to turn the conditioned sludge in the gravity drainage section of a BFP.

The use of BFPs by WWTPs has increased over the past twenty-five years. The dewatering technology, which was originally used in the pulp and paper industry, had a number of problems as it was introduced into the wastewater industry. These problems included poor mechanical performance and equipment durability that required large dosages of polymer and produced a poorly dewatered sludge cake. Although the BFP was able to produce a drier sludge and had a significantly lower energy requirement than the vacuum filters they were replacing, it was not until manufacturers had redesigned the machinery to withstand the conditions associated with municipal sludge dewatering that the BFP gained industry-wide acceptance (USEPA, 1986; USEPA, 1987; WPCF, 1983).

BFPs can dewater nearly all types of sludge with initial solids concentrations of 1 to 6% to final cake solids that range from approximately 12 to 50%, although the upper end of this range is not normally achieved. There are some sludges that the BFP is not capable of dewatering. These include sludges that are primarily chemically based and biosolids conditioned with lime (USEPA, 1986; USEPA, 1987). Table 2.1 shows typical performance parameters for the BFP with various sludge types. Data for WAS is presented from three different resources. It is obvious from the wide range of cake solids presented in the literature that there is a discrepancy in the perceived performance of WAS on a BFP. One resource, *Basic Maintenance of Belt Filter Presses* distributed by WEF, even presented very different values in two of its tables. In the first table, the range of expected cake solids reported was 16-32% for WAS. In a later table, the expected cakes solids is presented as 16% and the minimum is 13% for thickened WAS (WEF, 1997). It is important to recognize that this document is marketed to BFP operators and plant managers who use BFPs on their site. These wide ranges of values would suggest to an operator whose BFP is operating at the lower end of the range that there is some operational change that could be made or some other polymer that could be used to increase the performance of the BFP. In actuality, the BFP may already be operating at its peak due to the nature of the WAS. Based on the results of this project and the responses from the plant survey provided in Chapter 4, the values for the upper range of cake solids with WAS are overestimated. The data presented by the WPCF and the second set of data presented by WEF seem to be the most realistic.

Table 2.1: Typical Dewatering Performance of Belt Filter Presses (WEF, 1997; USEPA, 1987; WPCF, 1983)

Sludge Type	Feed Solids Concentration (%)	Polymer Utilization (lb/ton)	Cake Solids (%)
Raw Primary (P)	3-10	2-9	28-44
Waste Activated (WAS)	1-4	6-20	12-20[1]
	0.5-4	2-20	20-35[2]
	1-4	2-4	16-32[3]
	4	10	13-16[4]
P+WAS	3-6	2-10	20-35
P+Trickling Filter (TF)	3-6	3-20	20-40
Anaerobically Digested			
P	3-10	2-10	25-36
WAS	3-4	4-20	12-22
P+WAS	3-9	3-15	18-44
Aerobically Digested			
P+WAS	1-3	4-15	12-20
Thermally Conditioned			
P+WAS	4-8	0	25-50

[1]WPCF (1983), p. 115.
[2]USEPA (1987), p. 87.
[3]WEF (1997), p. 10.
[4]WEF (1997), p. 37.

A 1994-1995 survey by the WEF reports that 25% of small, 50% of medium, and 56% of large publicly owned treatment facilities use BFPs in their operations (WEF, 1994). The widespread use can be attributed to several factors. First, design and performance improvements made the utility of BFPs span a wider range of treatment plant sizes. These improvements include increasing the diameter of the roller shafts and using more durable bearings. With these changes, mechanical failures are now limited and maintenance of the machinery has been made more user-friendly (ASCE Task Committee, 1988; Dembitz, 1978; USEPA, 1987; WPCF, 1983).

With the increase in use of BFPs has come numerous studies and reports on their operation and performance and the comparison of this dewatering method to other

techniques. This background on BFPs is not exhaustive of all the related literature, but it does cover several of the most significant studies. Andreasen and Nielsen (1993) compared four dewatering devices with three sludge types. The dewatering equipment tested included a BFP, a solid bowl centrifuge, a press centrifuge, and a membrane filter press (also called a plate and frame press). Their study found that the cheaper dewatering equipment (BFP and solid bowl centrifuge) produced cakes with lower solids content than the more expensive devices (press centrifuge and membrane filter press). Johnson et al. (1992) discussed a series of tests performed on the BFPs at the Skinner Filtration Plant in southern California to identify the operational parameters critical to BFP efficiency and optimization. The presses typically operated at 500-600 dry lbs/hr and produced cakes with 18-25 % solids, both of which were lower than the manufacturer's specifications of 750 dry lbs/hr and 30% solids cakes. Although the presses did not meet specifications in terms of sludge production and cake solids, the plant considered the operation of the BFPs successful due to the minimal operator attention required. The authors presented the following operational parameters as critical to the effective operation of BFPs: solids feed (quantity and characteristics), influent sludge flow rate, polymer dosage, belt speed, and belt tension.

Lecey and Pietila (1983) presented a general overview of a BFP including the impact of operating variables on productivity and cost and the various stages of the dewatering process. The authors discussed five mechanical variables of the BFP: belt tension, belt speed, belt material, belt washing, and the number of rollers. Also discussed is how the sludge characteristics will change the performance of the BFP and what steps can be taken to optimize the efficiency of the dewatering process.

2.2 The Role of Water

Because the ultimate goal of sludge dewatering is to separate as much water from the solids as possible, a clear understanding of the role water plays in sludge particles is very necessary. In a valuable review of the nature of water in sludges, Vesilind (1994) provided an improved explanation of the physical behavior of water at surfaces. In past research on sludges, "it has been assumed that the water that surrounds the particles behaves as ordinary water, and that this water has all of the chemical and physical properties of common water" (Vesilind, 1994). In general, there were assumed to be only two types of water in sludge – bulk water and bound water. The author suggested that actually three different types of water make up what is commonly referred to as bound water. These are "water captured in the interstitial spaces within flocs and within cells, vicinal water on the surfaces of solids, and water of hydration." A fourth type of water is free (bulk) water, which is not associated with and not influenced by solids particles. Interstitial water is that which is trapped in the crevices and interstitial spaces of the flocs and organisms and is free to move when this confinement is removed. When the sludge floc or the microbial cells which hold this water are destroyed the interstitial water can become free water. Vicinal water consists of "multiple layers of water molecules held tightly to the particle surface by hydrogen bonding". Because of the intense force which holds the water molecules to the particle surface, the vicinal water is not free to move like interstitial water. Water of hydration is bound chemically to the particles and can only be removed by expenditure of thermal energy.

Mechanical dewatering is designed to remove both bulk water and interstitial water, with bulk water being the easiest to remove via drainage or thickening. Mechanical forces are required for the release of interstitial water by compressing or destroying the flocs. In order to remove vicinal water mechanically, prior conditioning is necessary. This conditioning would need to reduce the surface area of the particles, thus decreasing the availability of binding sites for vicinal water. Water of hydration cannot be removed with mechanical means, as previously stated. Based on this information, the limit of mechanical dewatering is the fraction of water that is vicinal plus water of hydration. If an accurate measure of the distribution of water in a given sludge could be made, the Vesilind (1994) theorized that it may be possible to estimate the highest cake solids concentration that could be achieved.

2.3 Sludge Conditioning

One of the most important aspects of sludge dewatering is proper conditioning. Sludge conditioning incorporates many issues, including polymer selection, polymer dose, mixing regime, temperature, pH, and cation interactions. The wastewater treatment plant staff must address each of these issues to ensure successful dewatering.

Novak and Haugan (1979) performed one of the early studies on sludge conditioning. In their work they aimed to better define the mechanisms for sludge conditioning by providing an understanding of the physical and chemical properties of activated sludge flocs and clarifying the relationship between biocolloids and the floc matrix. The authors presented the hypothesis that an understanding of the mechanisms should lead to improved sludge conditioning techniques and reduced chemical costs.

Their research utilized the time of filtration with the Buchner funnel and the CST tests to measure sludge filtration rates. Because of the less than accurate results obtained with the CST test when analyzing dilute and rapidly dewatering sludges, the method of choice for most analyses was the Buchner funnel method. The conditioning was done with two fully charged cationic polymers: a high molecular weight, dry polymer and a low molecular weight, liquid polymer. By varying polymer dose, mixing speed, and mixing time, Novak and Haugan (1979) were able to describe an adsorption model for activated sludge flocs. In their model, the activated sludge flocs are represented as a matrix to which natural anionic colloids are weakly adsorbed. The adsorption of anionic colloids to the floc is enhanced by dissolved cations which cause the coagulation of supernatant colloids through charge neutralization. Their study also found that when conditioning is done under intense mixing, large quantities of biopolymer are desorbed, which increases chemical conditioning requirements, and that activated sludges are more resistant to disruption and deterioration than those conditioned under gentle mixing conditions.

2.3.1 Polymers

Advances in chemical conditioners that aid the dewatering process have increased the use of BFPs. The chemical conditioners, which are also called polymers or polyelctrolytes as described by Lotito et al. (1990), cause the sludge to flocculate and release its free water. The free water easily drains from the sludge in the gravity drainage zone resulting in an approximatly 50% reduction in volume and a total solids concentration of 6 to 10%. The flocculated sludge can withstand the pressure and shear generated during its movement over the rollers, causing the release of additional moisture and transforming the sludge into a semi-solid state. At this time, polymers are the only

substance that can produce these necessary characteristics for BFP dewatering. There are metal salts, such as $Fe(Cl)_3$, which can be used in conjunction with polymers to enhance conditioning but cannot be used alone as the sole source of conditioning.

Polymers are supplied to the user in either a dry or concentrated solution form. These organic chemicals can have cationic charges ranging from less than 10 mole percent to greater than 25 mole percent. The molecular weights of polymers vary from less than 1×10^5 g/mole to over 8×10^6 g/mole (USEPA, 1987). Prior to being used, either form of polymer must be diluted with water to a 0.3 to 0.8% feed solution. Poduska and Stroupe (1980) suggested that when the long molecular chain polymer is diluted, it uncoils more fully exposing more charged sites. The sludge particles, which have a net negative charge, can collect on the oppositely charged sites of the cationic polymer resulting in more effective flocculation. Although this dilution adds additional water to the sludge (on the order of 1 to 10% by volume), the increased volume of filtrate released at a faster rate offsets the negative impacts of the extra water. The authors explained that excessive dilution would lead to a decline in dewaterability due to poor flocculation of the sludge (Poduska and Stroupe, 1980).

2.3.2 Polymer Dose

Polymer dose, which is a measure of the mass of active product of polymer being added to a mass of dry solids (typically in units of pounds per ton), is an important part of dewatering. For any given polymer and sludge, there is a lowest possible dose which provides optimum conditions for dewatering on a BFP (i.e., produces the highest cake solids with a high capture efficiency). As the characteristics of either the polymer or the solids change, dose adjustment may be needed. Solids characteristics are subject to

seasonal, daily, and even hourly variations that will affect the polymer demand for effective conditioning. Because of these variations, an operator must have a clear understanding of an optimum polymer dose. A polymer dose lower than this optimum will result in the formation of an unstable floc which cannot withstand the high-pressure shear zone. A sludge that is underdosed will squeeze through the belts, blocking drainage of the filtrate. This condition is called belt blinding. A polymer dose that is too high will cause the conditioned sludge to stick to the belt material, also causing blinding. Another indication that the sludge is overdosed is the sludge will appear foamy on the front end of the gravity drainage section where the conditioned sludge exits the flocculator and falls onto the belt. At an extreme overdose, thin strands of polymer will stretch between the top and bottom belts as they separate at the end of the BFP. An operator of a BFP can use these indicators to ensure that the sludge is being conditioned at an appropriate dose for the given conditions (USEPA, 1987).

The methods described above to determine optimum polymer dose rely heavily on operator observation and interpretation. One means available to quantify the state of sludge conditioning is with a streaming current detector (SCD). This device is "an eletrokinetic analyzer for characterizing charge properties of particles in aqueous suspensions" (Abu-Orf and Dentel, 1997). The SCD has been used in water treatment extensively, and Abu-Orf and Dentel (1997) evaluated its applicability to monitor polymer dosages with centrifuges and BFPs at wastewater treatment facilities. Most wastewater solids have a negatively charged surface, and the cationic polymer serves to neutralize this charge. As the charge on the solids approaches zero, the solids can agglomerate forming larger and stronger flocs. Because charge neutralization typically

indicates optimal solids destabilization, the SCD can be used to monitor this process. Their study found that near-zero SCD readings in the filtrate from the BFP coincided with optimal dewatering. Optimal dewatering conditions were determined by cake solids concentrations, filtrate turbidity, filtrate viscosity, conditioned solids filterability times and capillary suction time. The authors concluded that charge neutralization, as indicated by a zero reading on the SCD, is a key mechanism in solids conditioning. Igarashi et al. (1993) used the SCD to measure the collodial charge of the filtrate from BFPs and found optimum doses corresponded to a streaming current near zero. Dentel and Wehnes (1988), using capillary suction time to measure dewatering potential, showed that a streaming current near zero for conditioned solids and slightly negative in the filtrate corresponded to good dewaterability. By continually maintaining proper polymer dosage, many of the problems discussed by Abu-Orf and Dentel (1997) associated with excessive polymer in recirculation and discharge flows could be minimized.

2.3.3 Mixing

The mixing regime for sludge and polymer, which includes mixing time and mixing intensity, has been studied extensively to find the conditions under which the combination of these will be optimized. Werle et al. (1984) studied the effects of polymer conditioning under high stress on the filterability of alum, activated and primary sludges. Three parameters that were suggested to most significantly affect filtering rates are polymer dose, mixing time (t), and mixing energy or velocity gradient (G). The specific objectives of their study were to:

1. Determine the effects of polymer dose, mixing time, and mixing energy on the filterability of sludges;

2. Simulate the high-stress conditions of mechanical dewatering processes; and
3. Determine if jar tests adequately predict optimal polymer dose and mixing energy input (*Gt*).

The alum sludge was conditioned with an anionic polymer, while the activated and primary sludges were conditioned with a cationic polymer. Polymer was added to a volume of sludge and mixed at a specified rpm for a given length of time. Samples of conditioned sludge were withdrawn and analyzed using the CST apparatus. The mixing time and mixing intensity were varied from 15 seconds to 3 minutes and 250 sec^{-1} to 1215 sec^{-1}, respectively.

Their work found that the mixing intensity (*Gt*) was a critical factor in determining optimum polymer dose. For a given polymer dose, any combination of *G* and *t* which results in the optimum *Gt* value within a range of *G-t* ratios will give optimum dewatering results. They showed that as mixing intensity increased, polymer requirements increased and that there is a mix time and/or mix intensity that will maximize filterability for a given polymer dose. Also, they found that using a conventional jar test apparatus for conditioning tests almost always underpredicted required doses for effective conditioning. This is due to the low *G* values generated during this test which does not adequately represent the high-stress mechanical dewatering process (Werle et al., 1984).

Novak et al. (1988) examined the conditioning of an activated sludge and an alum sludge using a variety of polymers at several dosages to determine if the best polymer at one mixing intensity (*G*) is the best polymer under all mixing conditions (*Gt*). Their study extended the work done by Werle et al. (1984) by testing several polymers with

each sludge. The experimental methods used by Novak et al. (1988) were identical to those presented by Werle et al. (1984). Three different polymers were used to condition the two sludges used in their study. The activated sludge was conditioned with cationic polymers, and the alum sludges were conditioned with anionic polymers. The sludge samples were mixed at the desired speed. At given time intervals, samples of the conditioned sludge were withdrawn and dewatering rates were measured using a CST device. Four key conclusions were made from their work:

1. Proper conditioning of alum and activated sludges can prevent deterioration of floc integrity resulting from high mixing conditions and can allow efficient use of high pressure dewatering processes, like a BFP.
2. As *Gt* increases, polymer dose requirements for effective conditioning increases for both alum and activated sludges.
3. At high mixing energy inputs polymer selection for proper conditioning is more important than at low mixing energy inputs.
4. The specific activated sludge used during these tests appeared to be resistant to the effects of polymer overdosing.

An explanation of why polymer overdosing does not occur with activated sludge was presented using the activated sludge floc model proposed by Novak and Haugan (1979). Their model suggests that activated sludge consists of large flocs and smaller anionic biocolloids. Conditioning polymer is primarily used to coagulate the biocolliods through charge neutralization. At low polymer doses, most of the cationic polymer is used to coagulate the biocolliods. As polymer dose increases, large bioflocs begin to compete with biocolliods for polymer, and the bioflocs become a sink for the polymer.

The best dewatering occurs at the polymer dose that results in a zero charge of the floc. Because a significant amount of conditioning occurs prior to the polymer dose required for charge neutralization, an optimal polymer dose is often selected well below that required for charge neutralization. The additional polymer between the optimal and the zero charge dosages is consumed by the large flocs resulting in further charge neutralization with little additional dewatering enhancement. At dosages in excess of zero charge or polymer overdose, the large flocs consume the excess polymer, which prevents deterioration of dewatering (Novak et al., 1988).

2.3.4 Cation Interaction

Another aspect of sludge conditioning that has been investigated is the role soluble cations play in improving sludge settling and dewatering problems. Novak and Haugan (1979) found that chemical conditioning requirements were reduced when elutions containing $MgCl_2$ were added to sludge samples. They concluded that the role of salts in the sludge matrix is to increase the degree and strength of natural polymer adsorption to the sludge floc (Novak and Haugan, 1979). Higgins and Novak (1997a) examined the effect of cations, specifically Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, on flocculation, settling and dewatering of mixed populations from activated sludge systems to define a cation balance that optimized settling and dewatering characteristics. The goal of the research was to provide a diagnostic tool that could be used "to assess full-scale activated sludge systems to determine if settling and dewatering (could) be improved by adjustments in the cation balance" (Higgins and Novak, 1997a). To test the effects, continuous-flow, bench-scale reactors were used to simulate the activated sludge process. Biological suspensions from the reactor were tested for dewatering characteristics using

the CST test and the SRF test. The thickened sludge from the reactor was conditioned with cationic polymer at final concentrations between 5 and 10%. The optimal dosage was that which resulted in the minimum CST.

The first part of their study assessed the impact of calcium and magnesium both separately and together on sludge characteristics. It was initially determined that when both calcium and magnesium were added to the feed of the reactor, the sludge exhibited the best settling and dewatering properties. To more clearly define this effect, increasing concentrations of calcium and magnesium were added to the reactor. When no salts were added to the reactor, nonfilamentous bulking occurred. As the concentration of calcium and magnesium increased in the feed beyond an initial concentration, sludge settleability improved. At the lowest cation concentration examined, SRF and CST indicated poor dewatering. The majority of improvement in SRF and CST occurred after the first incremental increase in concentration of cations. Their studies concluded that the minimum calcium and magnesium concentration necessary for dewatering as indicated by reasonable values of SRF and CST was in the range of 0.72-2.0 meq/L and that an equimolar ratio of calcium and magnesium was important for some of the activated sludge systems. A proportional increase in cake solids and floc density was also realized with an increase in calcium and magnesium concentration. This suggested that divalent cations decrease the amount of bound and/or inter-floc water creating a tighter bound network of exocellular polymers. This results in a denser floc with higher solids concentration. The studies also found that the increasing concentration of divalent cations decreased the optimal polymer dose for conditioning. This was thought to occur as a result of a change in particle size distribution and a decrease in the particle surface

charge due to cation addition. As the divalent cation concentration increased, the number of particles in the range of 5-50 μm decreased (Higgins and Novak, 1997a). Karr and Keinath (1978) reported that particles in the range of 1-100 μm had the most effect on dewaterability and that an increase in particle concentration in this size range would decrease dewaterability.

Higgins and Novak (1997a) next examined the effect of excess sodium in activated sludge systems, which has been shown to cause poor settling and dewatering of activated sludge. Sodium was added to the feed of the reactor with calcium and magnesium. The concentration of the calcium and magnesium was held constant, while the concentration of sodium was increased incrementally. When less than 10 meq/L of sodium was added to the reactor feed, no change in floc density, CST, SRF, or cake solids was recognized. At sodium concentrations greater than 10 meq/L, SRF, CST and effluent solids increased and floc density and cake solids decreased, indicating deterioration in the settling and dewatering properties of the sludge. The proposed explanation for this change in sludge property is that an ion-exchange process occurred with the divalent cations being displaced from the floc by the monovalent sodium ions. Because divalent cations are believed to act as a bridge between negatively charged sites within the biopolymer network, floc structure is weakened when the divalent cations are displaced by the monovalent cations. This was also shown by the decrease in floc strength as measured by resistance to shear at higher sodium concentrations. Ultimately, their work found that the ratio of sodium to divalent cations is important to the settling and dewatering properties of the sludge. At ratios less than 1:1 settling was slightly improved, and above this ratio, settling rates decreased and effluent suspended solids

increased. A ratio greater than 2:1 in terms of meq/L resulted in poor settling and dewatering. The authors concluded that their data supported the cation-bridging model rather than the double layer compression model for flocculation of activated sludge.

In a continuation of their previous work, Higgins and Novak (1997b) analyzed several full-scale activated sludge systems to assess the cation content in terms of the monovalent to divalent cation ratio and the calcium to magnesium ratio. These ratios were used "to determine if the cation content affected the settling and dewatering properties of the activated sludges" (Higgins and Novak, 1997b). In addition, adjustments were made to the cation concentrations according to the guidelines developed by Higgins and Novak (1997a) in an attempt to improve settling and dewatering. Lab procedures similar to those of the previous study were utilized for characterizing the sludge properties after conditioning and cation addition. The full-scale activated sludge plants were sampled for settling and dewatering properties and soluble cation concentration. The best-defined relationship of the data collected was between the monovalent to divalent cation ratio and SRF and CST values. The data indicated that a monovalent to divalent cation ratio greater than 2:1 resulted in increased SRF values, suggesting deterioration of dewaterability.

After data collection, two of the plants were chosen for field testing of cation addition to improve settling and dewatering properties of the system. The first plant was found to be deficient in calcium as indicated by a calcium to magnesium ratio less than one. The second plant was magnesium deficient with a calcium to magnesium ratio much greater than 1. After addition of the appropriate cation to bring the calcium to magnesium ratio closer to the optimum value, both plants experienced improvements in

settling and dewatering properties. During a separate study at a municipal plant, NaOH and $Mg(OH)_2$ were added to the system for pH control. During periods of NaOH addition the plant experienced poorer settling than during $Mg(OH)_2$ addition. The plant also saw a dramatic decrease in polymer demand for conditioning and dewatering during $Mg(OH)_2$ addition. This supports the previous findings of Higgins and Novak (1997a) in that polymer demand can be reduced with addition of appropriate cations.

The authors concluded that the soluble cation content in an activated sludge system should be investigated when flocculation, settling and dewatering problems occur. They suggest using the monovalent to divalent cation ratio and the calcium to magnesium ratio, expressed on a milliequivalent basis, as parameters for evaluating a cation balance. The guidelines for these ratios should ensure an improvement in settling, dewatering and effluent suspended solids concentration for an activated sludge system (Higgins and Novak, 1997b).

2.4 Laboratory Methods for Predicting Sludge Dewaterability on BFPs

Several tests are presented in the literature that are used to predict the dewatering capability of BFPs. Each laboratory method attempts to replicate a particular aspect of the BFP and use this replication as a means to predict overall performance. Each method has advantages and disadvantages that must be considered when determining which laboratory method to use for BFP performance predictions.

2.4.1 Specific Resistance to Filtration

The SRF test measures the resistance of a sludge to the withdrawal of water either by vacuum or pressure. In general, the higher the specific resistance, the more difficult it

is to dewater a sludge, and the lower the specific resistance the easier a sludge is to dewater (Karr and Keinath, 1978). Coakley and Jones (1956) first discussed in their investigation of various theories of filtration the use of the specific resistance test as applicable to sewage sludges. The authors used the apparatus similar to that of a Buchner funnel test and outlined in their paper the proper procedures and data analysis for the SRF test. Since this introduction, the SRF test has been used extensively to characterize sludge dewatering.

Gale (1967) further explained the theories presented by Coakley and Jones (1956) in an attempt to clarify misconceptions concerning the true significance of SRF and the units for specific resistance. Gale (1967) started with the differential equations that define specific resistance and stepped through the development of the equations that relate volume of filtrate with time. Gale explained the difference in the units that were being used by early investigators of SRF. Originally, the units for SRF were reported as s^2/g. The author showed that SRF with units of cm/g could not be numerically compared to those values with units of s^2/g based on the acceleration due to gravity not being incorporated into the latter value.

Karr and Keinath (1978) discussed two limitations of the SRF test for dewaterability not previously well documented in the literature. The first dealt with the role of blinding of the sludge and filter media in resistance data. They found that blinding was dependent on the solids concentration and that specific resistance values should be standardized using a blinding index value. In addition, the specific resistance test does not account for all properties of a sludge that are important in determining how well a sludge should dewater on newer types of dewatering equipment. These include

pick-up and release characteristics and particle resistance to shear. They concluded that factors in addition to SRF must be considered when determining the dewaterability of a sludge in practice.

Tosun et al. (1993), in an attempt to resolve confusion in the literature about the use of SRF, gave a historical summary of the development of SRF and reviewed experimental techniques used in the determination of SRF. One of these techniques is the Buchner funnel test, which is the most commonly used method for determining SRF. To perform this test, filter paper and a funnel are used to drain a given volume of sludge. Using either the pull of a vacuum or applied pressure, the filtrate is drawn through the funnel and collected in a calibrated reservoir. The volume (V) is recorded as a function of time (t). The specific cake resistance is obtained from the slope of the straight-line plot of t/V versus V. There is speculation, although, as to whether the Buchner funnel tests actually simulate the filtration process. Tosun et al. (1993) explained that once the solids in the supernatant liquid at the top of the filter cake have settled the process is more like flow through a packed bed than filtration. In addition, the process changes from filtration to cake dewatering once the level of supernatant reaches the surface of the cake. Based on this information, the authors concluded that the Buchner funnel test could be used to obtain qualitative information on the filterability of sludges, but quantitative conclusions were questionable (Tosun et al., 1993).

Several authors have disputed the usefulness of the SRF value as a means for measuring dewaterability. Vesilind (1988) agreed that SRF was based on sound theory and was an effective measure of how well a sludge could yield water by filtration. But, he claimed that SRF was a cumbersome test that provided poor estimates for actual

vacuum or pressure filter performance. Knocke and Novak (1987), in a discussion of an article by Christensen and Dick (1985), and Barber et al. (1997) pointed out that the two main disadvantages of SRF were its being cumbersome and time consuming in nature. The authors suggested that the standardization of the specific resistance procedure was needed in order for the test to serve as an index or relative measure of dewaterability, similar to the BOD test as an index of wastewater strength. They concluded that strict interpretation of the data obtained from a SRF test for direct process design was lacking in validity.

2.4.2 Capillary Suction Time

Gale and Baskerville (1967) introduced the theory of CST as an alternative to the SRF test for a quick measure of the filterability of suspensions. CST, by definition, is the length of time required for a specific volume of filtrate to be withdrawn from a small reservoir of sludge and pass between two concentric circles when it is subjected to the capillary suction pressure of a standard absorbent filter paper (Baskerville et al., 1978; Karr and Keinath, 1978). The filtrate flows radially outward from the sludge sample that is contained in an open-ended cylinder resting on the filter paper. A short CST is considered indicative of an improved filtrate release from a well flocculated sludge, while a long CST is representative of a poorly flocculated sludge in which little filtrate has been released. Baskerville and Gale (1967, 1968) presented experimental procedures, methods of operation, and apparatus diagrams for the CST test.

CST was presented as a test to ensure that the sludge was being conditioned with the correct dose of polymer for filterbelt pressing (Baskerville et al., 1978). Because of its simplicity and quick results, CST has become a widely used tool to measure the

effects of chemical conditioners on sludge dewaterability. Vesilind (1988), although, pointed out that this is a purely empirical test that is not based on a theoretical analysis of sludge dewaterability and that it cannot be properly used as a research tool. Because CST is dependent on sludge solids concentration and the instrument being used, CST values are unique to a given sludge at a given plant and should not be compared from one plant to another. In an attempt to provide a theoretical model for the CST, Vesilind described the "filterability constant," which is a measure of the ease with which sludge yields its water. This constant, not CST, should correlate with SRF because both are fundamental measures of dewaterability. Thus, the ability of a sludge to yield its water should be reported as the filterability of the sludge, rather than CST (Vesilind, 1988). It is important to note that Vesilind only tested unconditioned sludge in his study; therefore, the application of this principle to conditioned sludges is left for further study.

Christensen et al. (1993) discussed the use of CST and SRF to prevent overdosing of sludge conditioner chemicals and the mechanisms associated with overdosing. SRF and CST measure a resistance to filtration, which can be divided into two categories: an apparatus resistance and a sludge resistance. In the context of measuring the dewaterability of sludges, the sludge resistance part of SRF and CST is the important variable. A modified CST was proposed in which corrective terms are included to account for the apparatus resistance, the filtrate viscosity, and the sludge solids concentration. In examining overdosing, CST, SRF, and filtrate viscosities were found to increase as polymer dose increased. CST measured small differences in dewaterability over a wide range of polymer dosages around the optimal dosage due to the apparatus resistance masking the sludge resistance. CST predicted a lower optimal polymer dosage

than SRF showing that these tests do not always equally characterize sludge dewaterability. The authors concluded that the viscosity measurements on the sludge filtrate/supernatant may identify the optimum polymer dosage more closely than that determined by CST measurements.

Several authors discussed the limitations of the CST test. Karr and Keinath (1978) reported that CST measurements were more sensitive to changes in fragile settleable solid concentrations than SRF measurements. This solids fraction represents "those solids which are too fragile to be removed by filtering through a 100 μm mesh, yet are large enough to settle under quiescent conditions" (Karr and Keinath, 1978). This phenomenon is explained by the small volume of filtrate that is removed from the sludge during the CST test and the composition of the solids in the filtrate. The fragile settleable solids portion of the total settleable solids has a tighter packing pattern. Because CST is more sensitive to pore size and packing characteristics of the solids, the CST values will increase as the fragile settleable solids concentration increases. Poduska and Stroupe (1980) presented two factors that complicated laboratory studies of flocculation efficiencies. First, the 18-mm CST reservoir tube is often smaller than the individual sludge floc particle. This yields a biased result of the CST value. Second, the 10-mL CST reservoir volume is an order of magnitude less than the minimum volume of sludge needed to accurately simulate full-scale mixing. Also, removing only a 10-mL sample of flocculated sludge is not practical since a single floc may approach or be larger than 10-mL (Poduska and Stroupe, 1980).

During their studies, Poduska and Stroupe (1980) constructed a 50-mL capacity reservoir tube with a 43-mm diameter in an attempt to overcome the difficulties in

pouring directly into the 18-mm reservoir from a larger flocculation vessel. This proved ineffective since it was determined that a minimum sludge sample of 100 mL was required to eliminate adverse bench-scale mixing factors. Thus, the results were based on a disproportionate quantity of filtrate being transferred to the reservoir, and no correlation with dewatering performance could be shown.

Barber et al. (1997) presented several drawbacks to both CST and SRF. First, both tests are limited to thickened solids with a concentration of 15,000 mg/L or greater, and when unthickened sludge samples are tested, the rate of water release from the sludge is too fast to obtain an accurate or precise measurement. Also, if a plant uses chemical conditioning to improve thickening, this will affect both CST and SRF measurements taken after thickening and assessing the inherent biological characteristics of the solids would not be possible. A final drawback presented is that CST requires the test to be normalized for one solids concentration, which requires multiple samples to be prepared and analyzed to produce one test result.

2.4.3 Centrifuge Test

Another quick measure of dewaterability is the centrifuge test. Staff at the Eastman Chemical Company's WWTP in Kingsport, Tennessee developed this test as a result of declining performance of their BFPs. The operators needed a quick, quantitative method to determine small changes in the dewatering characterics of the activated sludge. Referring to Vesilind's (1994) discussion of the various types of water associated with biological sludge and the limitations of mechanical dewatering to remove certain portions of this water, the staff began the development of a more appropriate process control method. The test involved spinning activated sludge mixed liquor samples for 10

minutes at 45,100 gravities in a high-speed centrifuge equipped with a fixed-angle rotor. After centrifugation, the centrate was decanted and the compacted sludge pellet was removed from the centrifuge tube. The sludge pellet was weighed wet and then dried at 103°C to a constant weight. The difference between the wet weight and dry weight was used to determine total solids content. This experimental method was chosen because the spin time was suitable for routine process control and the centrifugal acceleration was slightly less than the 48,200 maximum gravities of the centrifuge, which would reduce equipment stress. This centrifuge test was called $Spin_{45K}$. The staff considered solely using SRF and CST to assess dewatering changes, but discarded them for various reasons, described above (Barber et al., 1997).

In order to verify the correlation between the $Spin_{45K}$ and BFP cake solids, samples of activated sludge were taken multiple times per week for 8 months. To compare the $Spin_{45K}$ method with an accepted dewaterability measure, all of the samples were also tested using CST. The correlation coefficient (r) between $Spin_{45K}$ and the BFP cake solids was 0.859, while the correlation between CST and cake solids was 0.775. Thus, $Spin_{45K}$ had a stronger relationship to cake solids than CST and the dewatering characteristics of the sludge affected the performance of the BFP. Based on the r^2 value of 0.738 for the correlation between $Spin_{45K}$ and cake solids, 74% of variability in cake solids was related to sludge dewatering characteristics. This suggested that other operating parameters, including polymer dose, belt tension, and belt speed, only account for 26% of the variability and that more focus should be put on the activated sludge process operations than on the dewatering equipment (Barber et al., 1997).

With this new information and technique to assess the dewatering characteristics of the biological solids leaving the activated sludge units, the plant staff was able to investigate process control strategies for the activated sludge process. The overall goal of these changes was to reduce the predominance of zoogloeal bacteria in the sludge which were present in excessive levels and thereby changed the dewatering properties of the sludge. Although it was difficult to quantify the effect zoogloeal bacteria had on dewatering, the plant staff knew that the increased levels of zoogloeal bacteria occurred at the same time as the decline in performance of the BFPs. After making process changes to the activated sludge units, $Spin_{45K}$ tests showed an increase in solids from 7.5% to 14% over a four-month period. This increase corresponded to an increase in cake solids from 10% to 15% and higher on the BFPs. (Barber et al., 1997)

Based on the success of the $Spin_{45K}$ test with Eastman's WWTP, this is obviously a useful measure of sludge dewatering potential. The $Spin_{45K}$ test could be used to detect changes in an activated sludge process that would ultimately affect the performance of the dewatering process. Overall, this test provided a means to decrease chemical addition for sludge conditioning and increase cake solids, while improving the complete operation of the WWTP.

2.4.4 Crown Press

The Crown Press (Figure 2.4), which is described in detail in Chapter 3, is a fairly new piece of equipment used to simulate BFP dewatering. Severin and Collins (1992) used the Crown Press in side by side comparison tests to simulate the wedge and high pressure zones of the Carter and Rexnord Presses. They reported that the Crown Press was able to produce cake solids similar to those produced on the Carter and Rexnord

Presses. The authors proposed that the Crown Press could be used to predict BFP failure due to sludge overloading when sludge migrates off of the belts from both sides of the first roller. This phenomenon typically occurs when the belt speed is too low to handle the flow of sludge onto the gravity drainage section of the BFP. The authors stated that additional testing was necessary to substantiate this finding. Emery (1994) reported that the Crown Press was able to simulate both the wedge zone and high-pressure zone of the BFP. On all of the Crown Press simulations, however, severe belt blinding occurred. Because belt blinding constitutes a point of failure on the BFP, this conclusion was suspect.

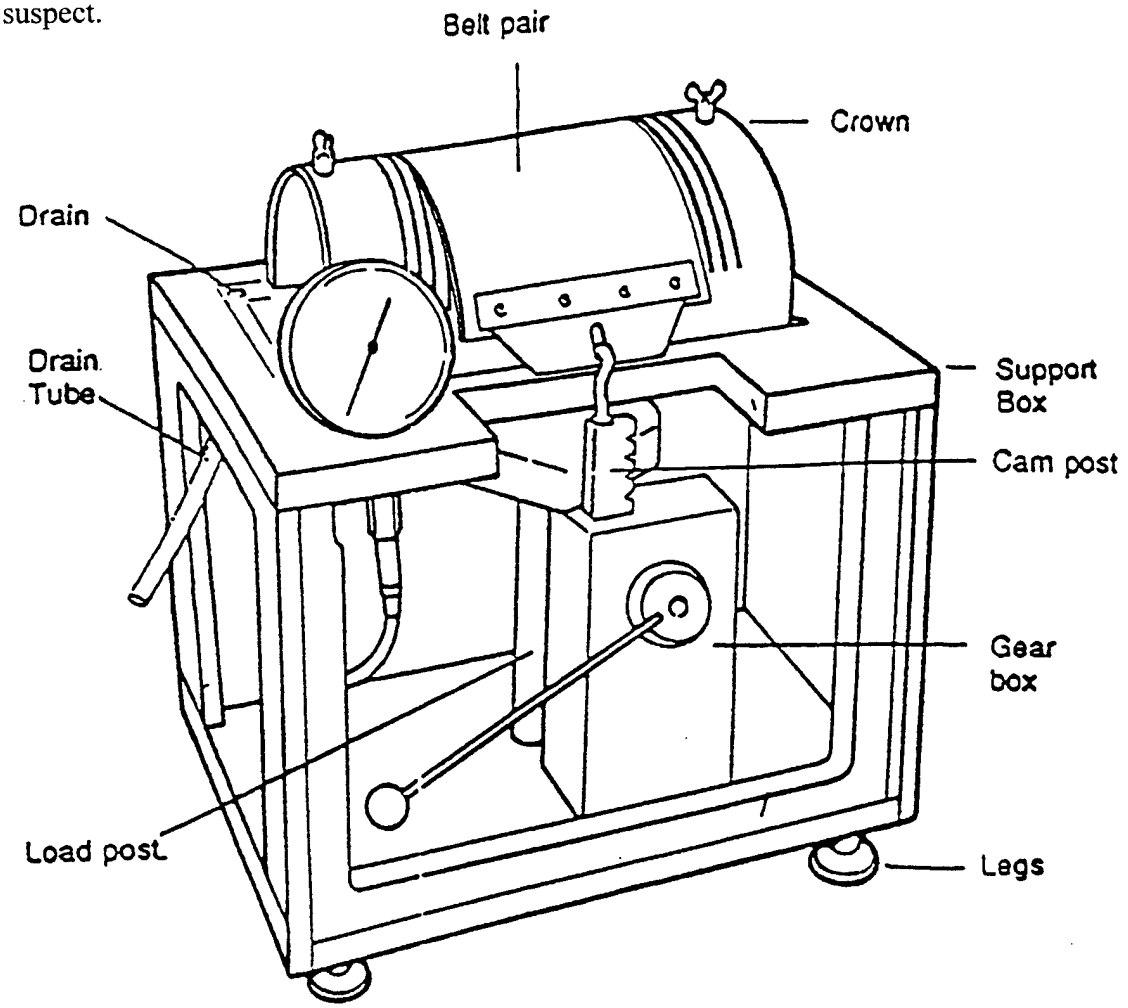


Figure 2.4 Schematic of the Crown Press (Neogen Corp.).

Galla (1996) and Galla et al. (1996) reported that the Crown Press was effective at simulating the operation of a BFP when proper belt tensions are used in pressing regime calculations. First, they determined that the Crown Press was capable of simulating roller-by-roller performance of the BFP. Unfortunately, this process was cumbersome and measurements collected on the BFP were subject to error due to the inaccuracy of determining the pressure at each roller. To overcome these problems, they developed a system for pressing conditioned sludge at different pressures for various lengths of time and expressed the data in terms of cake solids versus log(pressure*time). Because a single test on the Crown Press at a given pressure and time could simulate the entire roller-by-roller press sequence, this test was referred to as the single press test. They found that a series of Crown Press single press tests at several different times and pressures could produce cake solids which fell within a BFP operating region. These single press tests were used to successfully predict a conservative BFP operating region with given static and dynamic parameters. Galla et al. (1996) also showed that the Crown Press was effective at evaluating the performance of various polymers over a range of doses and the performance of belt fabric on two sludge types. During both of these evaluations, the single press test accurately predicted current BFP performance at three wastewater treatment plants. The Crown Press was also used to make predictions regarding performance of different polymers and belt types. However, these predictions were not tested on a BFP. A major objective of this project was to evaluate Crown Press predictions on BFPs. Figure 2.5 shows the Crown Press that was used in both this study and the study by Galla et al. (1996).

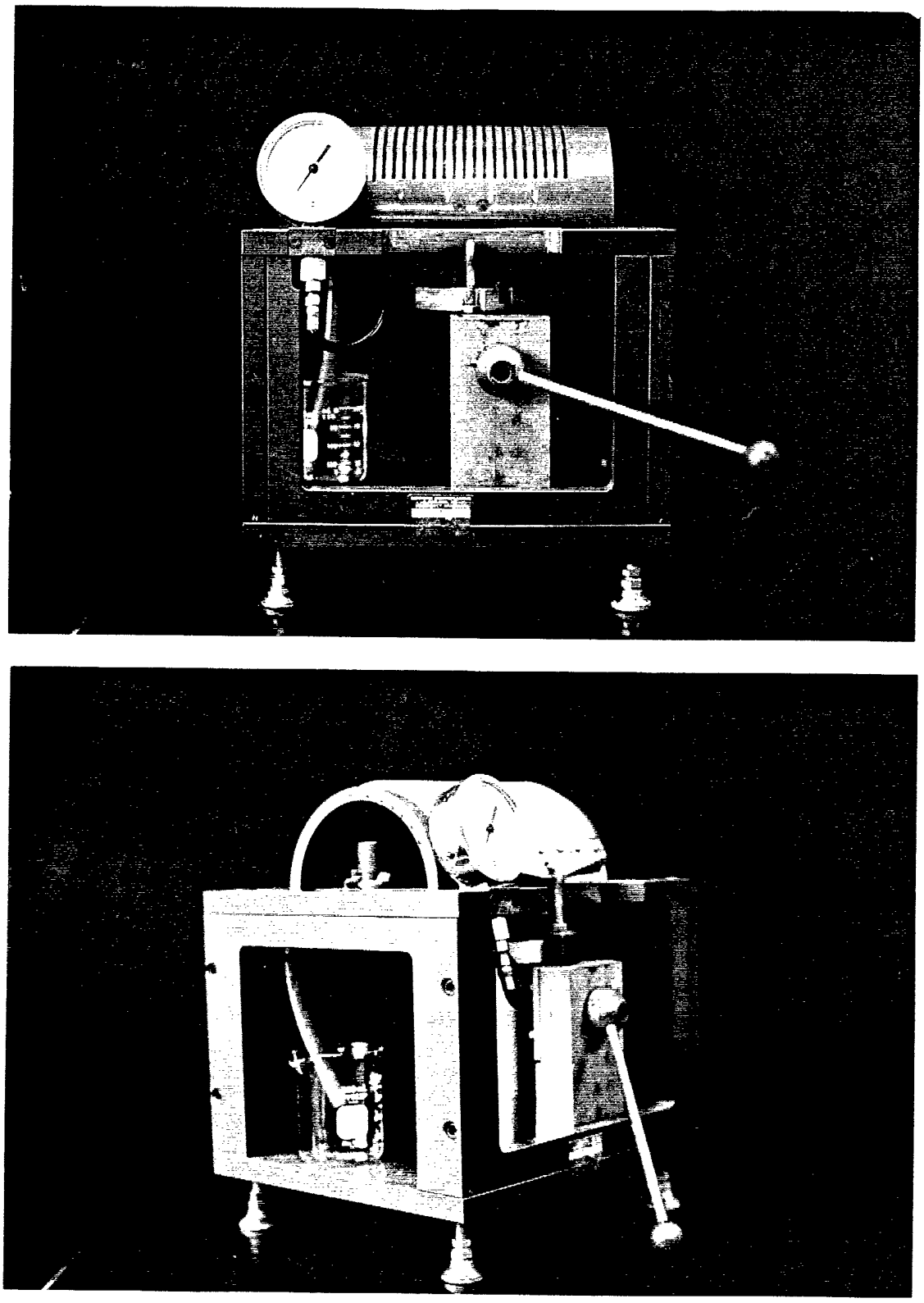


Figure 2.5 Photographs of the Crown Press used in this project.

2.4.5 Gravity Drainage

The gravity drainage test is a tool used to evaluate the effects of changes in either the sludge type, polymer type, polymer dose, belt type, or belt speed to the rate of filtrate drainage. This is done by placing the sludge cake on filter media, which is typically the BFP belt material being evaluated, and allowing the filtrate to drain into a graduated cylinder while measuring the rate of drainage. Poduska and Stroupe (1980) and Baskerville et al. (1978) described gravity drainage tests used to test whether a super-flocculated sludge would dewater. In their studies the BFP belt fabric served as the drainage material. The sludge was placed into a retaining ring or container, which was connected to a funnel to channel the filtrate. A graduated cylinder captured the filtrate, and the volume was recorded at regular time intervals. It was determined that this test more effectively evaluates sludge flocculation for dewatering and that the results from this test relate directly to flocculation effectiveness in a manner more meaningful than CST values (Poduska and Stroupe, 1980).

Emery (1994) and Galla (1996) used similar systems to that described above to evaluate filtrate volume as an indicator of successful dewatering on the Crown Press. Emery (1994) found a critical ratio of volume of filtrate after 60 seconds of drainage minus the volume of polymer plus water added to the volume of sludge. When the ratio was equal to or greater than this critical value, the sludge cake was capable of successful dewatering on the Crown Press. Galla (1996) found that this test was useful to determine the critical polymer dose at which a significant fraction of the free water in the sludge would drain after 60 seconds. When the polymer dose was less than the critical dose, the sludge/polymer slurry could not be pressed on the Crown Press. Although the gravity

drainage technique was useful, Galla (1996) used a jar test as a quicker measure of acceptable polymer dose during polymer evaluation with the Crown Press.

2.4.6 Wedge Zone Simulator

The Arus-Andritz Company developed the wedge zone simulator (WZS) to simulate the gravity drainage section and the wedge or first belt pressing zone of a BFP. The WZS (Figure 2.6) consists of two Plexiglas boxes, one inside of the other. The bottom box has holes drilled in it for filtrate drainage. A piece of BFP belt fabric lies in the bottom of the box. A 300 mL conditioned sludge sample is placed onto the belt fabric, and a second piece of belt fabric is placed on top of the sludge. The second box, which is smaller than the bottom box so that it fits tightly into the bottom box, is placed on top of the sludge and filter fabric (Novak et al., 1993).

First, the volume of filtrate that passes through the bottom filter fabric is collected in a graduated cylinder below the boxes for one minute. A pneumatic cylinder, which is pressurized by a compressed air tank, then applies a pressure to the top box, squeezing the sludge between the two pieces of belt fabric for two minutes. The total discharge volume is recorded, and the sludge cake is analyzed for percent solids.

Novak et al. (1993) used the WZS successfully to predict polymer dose requirements, filtrate quality, and cake solids for a BFP. The free drainage portion of the test was shown to be capable of predicting the optimum polymer dose for a BFP but could not accurately predict the filtrate quality and cake solids of a BFP. Novak et al. (1993) found that trends in final percent cake solids from varying pressures on the WZS correlated to trends in BFP final percent cake solids caused by varying the BFP belt speed, and thus, time under pressure.

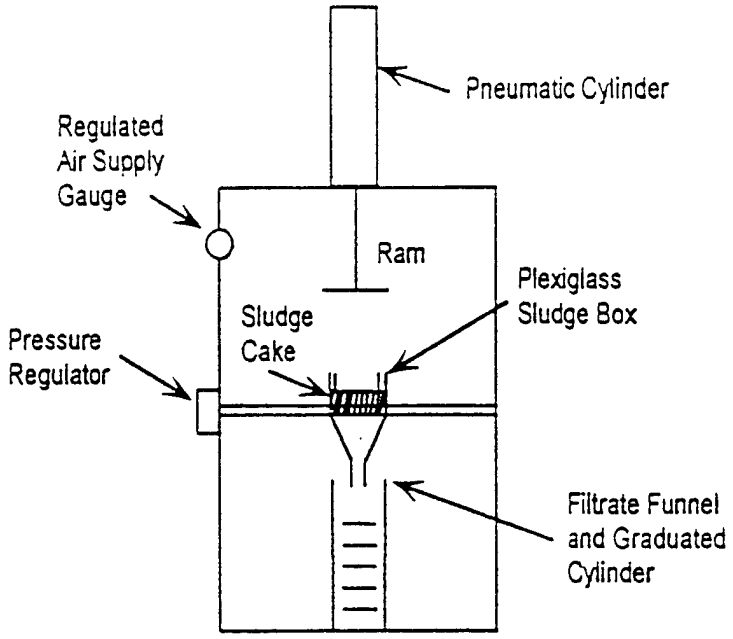


Figure 2.6 Wedge Zone Simulator.

2.4.7 Piston Press

Baskerville et al. (1978) and Halde (1980) described the use of the piston press for predicting the performance of the filterbelt press. The filterbelt press presented in the literature is similar to the early forms of the BFP (Figure 2.1) which only contained a wedge zone and a limited high pressure zone. In this older design the sludge was compressed between a filter medium on the bottom and an impenetrable surface on the top. This forced the filtrate to pass through the layer of sludge between the two surfaces and exit through the bottom filter medium. The piston press consisted of either a pneumatic or hydraulic non-porous piston which could be pressurized from above using compressed air. A sample of conditioned sludge was placed in the bottom of the piston on top of a piece of porous filter media. Filtrate was collected from a drain directly

below the filter media, which could be opened and closed to prevent loss of filtrate before pressure was exerted on the sludge sample by the piston. The piston press allowed the sludge to be dewatered at various pressures for differing lengths of time.

Baskerville et al. (1978) discussed two disadvantages of this particular laboratory method. The first was that drainage was possible only through the bottom surface of the sludge sample. The author suggested that this could be overcome to some extent by adding an absorbent medium to the bottom face of the piston. The second disadvantage was that the sludge cake underwent no externally induced shear or physical rearrangement during the pressing sequence as a sludge cake does on a belt press. The piston press would thus be expected to produce a lower cake solids than a filterbelt press would achieve for a given compression time (Baskerville et al., 1978). To simulate the shearing actions on the filterbelt press, the piston press described by Halde (1980) included means to rotate the piston. The revolving piston was fitted with wire gauze to increase the frictional resistance between the metal piston and the sludge sample. This was similar to the filterbelt press which used two wire gauzes on either side of the sludge cake to increase frictional resistance and created more intensive shearing. Overall, cake solids obtained from testing with the piston press were found to be comparable to filterbelt press cake solids at similar compression times.

2.4.8 Comparison of Methods

The laboratory tests described above are the accepted tools for measuring sludge dewaterability. Neither CST nor SRF incorporate pressure and press duration, which cake solids are dependent upon. For this reason, these tests cannot predict final percent cake solids from a mechanical dewatering process. The centrifuge test appears to be a

strong candidate for measuring changes in sludge dewatering potential. The $Spin_{45K}$ test is a quick and easy method to determine if sludge characteristics in the aeration basin that would affect dewatering have changed. The Crown Press and the WZS appear to be the best devices for simulating a BFP. Because the Crown Press has a closer replication of a high pressure/shear zone on a BFP, it may be able to more closely simulate and predict BFP performance and operating regions.

Galla et al. (1996) showed that the Crown Press can effectively replicate the operation of a full scale BFP, as discussed previously. With this understanding, it would be useful to determine how well a prediction of dewaterability with the Crown Press simulates actual BFP performance. This research continued the work of Galla et al. (1996) by determining cake solids that can be achieved with WAS when changes are made to operating parameters, such as time under pressure, belt lineal tension, polymer dose, and belt fabric, using the Crown Press. The Crown Press data was used to predict the cake solids from a BFP operating under the same parameters.

CHAPTER 3

MATERIALS AND METHODS

3.1 Plant Description

The WCRSA, Mauldin Road WWTP is a biological phosphorus removal plant that serves the greater Greenville, South Carolina, area. The design capacity of this plant is 40 MGD, and it typically handles 20 MGD with approximately 20% of its flow coming from industrial sources. The plant is currently using an 8 day solids retention time and a 27 hour hydraulic residence time. The flow diagram for the facility (Figure 3.1) shows that sludge from the primary clarifiers is pumped to the anaerobic digesters and that waste activated sludge from the secondary clarifiers is sent to the dissolved air flotation (DAF) tanks. BFPs, manufactured by Arus Andritz and Eimco, follow the anaerobic digesters and the dissolved air flotation tanks, respectively. Currently, very little of the Class B biosolids from the anaerobic digesters are being pressed. The liquid slurry that is removed from the digesters has a solids concentration ranging from 3.5% to 5% and is being land applied to agricultural fields without undergoing dewatering. The facility is currently paying a contractor $0.025/gallon to haul the slurry off-site.

As stated above, the plant utilizes biological processes to remove phosphorus from the wastewater. In this system, microbes release phosphorus in the anaerobic zone and take up phosphorus in the aerobic zone of the aeration basins. The mixed liquor from the aerobic zone that settles in secondary clarifiers is rich in phosphorus.

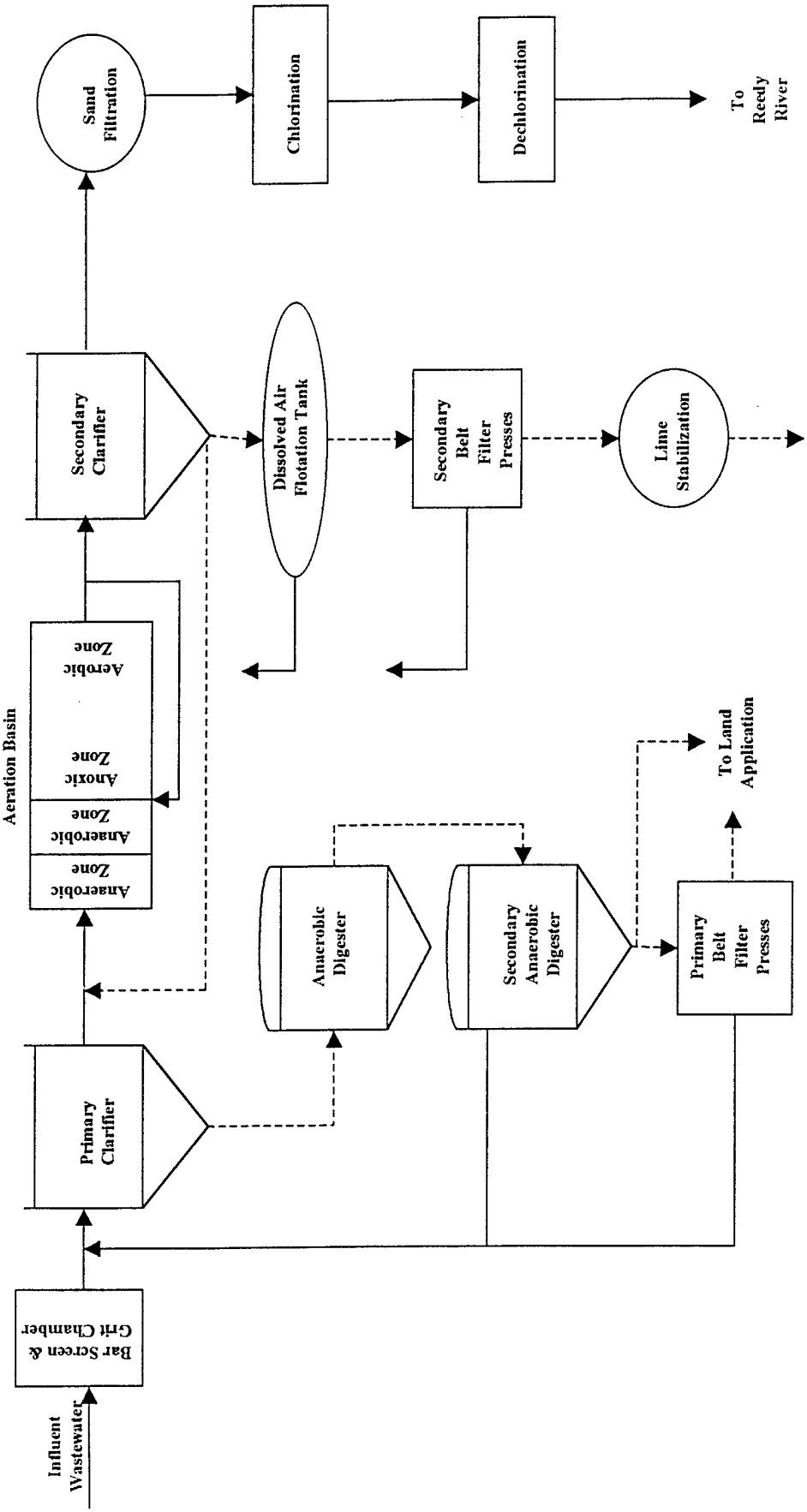


Figure 3.1: Mauldin Road wastewater treatment facility flow diagram. Solid lines represent liquid streams and dashed lines represent sludge streams.

If WAS were to be placed in the anaerobic digesters used for the primary sludge, the microbes would release the phosphorus into the supernatant of the digesters. The supernatant, which is sent to the head of the plant, would return to the liquid stream most of the phosphorus that was removed in the aeration basins. Therefore, the sludge from the aeration basins must be dewatered without any digestion. As shown in Table 2.1, undigested WAS typically is the most difficult type of sludge to dewater on BFPs. Because cake solids for WAS are in the low range of what can be achieved with BFPs, optimization of the process is very important.

The secondary sludge that is wasted from the secondary clarifiers is sent to the DAF tanks. The thickened sludge in the DAF tanks is skimmed from the surface and flows to the BFP facility. The sludge is conditioned with a high cationic charge, high molecular weight polymer solution, which is mixed from a dry polymer on site. The conditioned sludge is pressed on four 2.2 meter Eimco BFPs. Then lime, in the form of kiln dust, is added to the cake for stabilization. This process serves two purposes, both of which are required for Class A land application of biosolids. First, the lime raises the pH and increases the temperature of the mixture enough to reduce the fecal coliform levels. Also, the moisture content of the biosolid/lime mixture must be lower than 50%. The mixture has a moisture content of roughly 55-60% (40-45% solids) immediately after lime addition. To remove another 10% of the moisture, the biosolid/lime mixture is dried further on outdoor concrete pads.

The lime represents a large operating cost for WCRSA. Currently they are spending $ 45/ton for kiln dust and use approximately 75 ft^3/hr or 2.92 pounds of kiln dust per pound of dry sludge. This equates to an estimated $500,000 per year for kiln

dust. Polymer costs average $84,000 per year. Therefore, if the operation of the BFPs could be improved to achieve higher percent cake solids off of the BFPs, less lime would have to be added.

3.2 BFP Operating Data

Data was collected from WCRSA on several BFP operating parameters. Average final percent cake solids, the range of belt speeds used, and the range of hydraulic tensions used were obtained from Mauldin Road personnel. A technical service representative from Eimco provided information on the actual BFP machinery, including the number of rollers in the belt press, the diameter of the rollers, and the wrap angle of the belts. From December 1996 to August 1997, the primary belt press average final percent cake solids was 17.0% with a standard deviation of 1.9%, and the secondary belt press average was 14.2% with a standard deviation of 1.0%. Cake solids were determined by microwave analysis; as will be shown below, this tends to overestimate solids content by approximately 1.2%. The typical belt speed used on the BFPs is 21 ft/min, and this varies from 20-25 ft/min depending on the press. On the Mauldin Road BFPs, there are three locations where the pressure exerted on the belts can be changed. These are on the long belt, on the short belt, and on the aligning roller. Several years ago, the hydraulic cylinders, which control the pressure applied on the cylinders and ultimately the belt lineal tension, on Presses #2 and #4 were replaced. The newer cylinders are smaller in diameter than the older cylinders, and therefore use higher pressures than the old cylinders to achieve comparable belt lineal tensions. The pressures on the older cylinders are set at 450 psi for the long belt, 350 psi for the short belt, and

500 psi for the aligning roller. The pressures on the newer cylinders are set at 824 psi for the long belt, 641 psi for the short belt, and 915 psi for the aligning roller.

Prior to beginning testing, the belt speeds on all four presses were verified. Each of the presses has a digital belt speed indicator located on the press operating panel. To check the speed of the belt, a mark was place on the edge of the belt and the time it took this mark to pass between two fixed points on the press was measured with a stopwatch. These two fixed points were located 78.5 inches apart on the top portion of the belt press in the gravity drainage section. The initial belt speed checked was the normal operating speed of the particular press belt. The speed was then lowered incrementally to between 10 and 12 ft/min (indicator belt speed), and the times for each speed were recorded. The belt speed indicator on all four presses reported speeds lower than the actual speed of the belt. The difference between the actual and indicator belt speeds increased with increasing belt speed. Appendix A shows the correlation between indicator and actual belt speeds for all four presses. All of the belt speeds listed in this report are the actual belt speed.

3.3 Equipment

There were three main pieces of equipment used during the laboratory tests of this project. The Crown Press used by Galla (1996) was the primary device utilized for lab testing. In order to compare results from the Crown Press with accepted laboratory measures for dewaterability, a CST device and SRF set-up were also used. The CST device was borrowed from WCRSA, and the SRF test set-up was similar to that used by Galla et al. (1996).

3.3.1 Crown Press

The Crown Press (Figure 2.4), which was developed by the Neogen Corporation, was used as the main piece of equipment in this research project. The press is designed to simulate the dewatering action in the high-pressure zone of a BFP. This is accomplished by several components of the Crown Press. To simulate the roller surfaces of a BFP, a PVC pipe that has been cut in half-lengthwise serves as the crown. Belt fabric is placed over the crown, and a sludge patty is placed on top of the belt. A second belt stretches over the bottom belt and connects to hooks on either side of the crown. The bottom belt is roughly 7" x 12", and the top belt is 7" x 7". The hook on the front of crown is part of a rack and pinion system that pulls the hook down. The pulling of the top belt over the bottom belt squeezes the sludge between them exerting a pressure on the sludge. At the front of the crown is a pressure transducer. This transmits the hydraulic pressure being exerted on the crown to a gauge. The transducer is one square inch in area, therefore the pressure reading of the gauge can be related to the tension applied to the belt (Severin, 1997). During Galla's (1996) work with the Crown Press, several modifications were made to the Crown Press to facilitate quicker testing and they were utilized in this research.

1. The top belts were assembled as shown in Figure 3.2. The belt had a second metal plate attached to the end that would allow it to be held by the added stationary hook. This modification makes removal of the belt for cleaning quick and easy. The top metal was made of stainless steel and the bottom plate was made of aluminum. Between the top metal plate and the belt, an angled stainless steel plate was added to

direct filtrate from the top belt into the filtrate catch channel. The belt was placed between the three plates and held in place with screws and nuts. Holes in the belt were made with a heated nail.

2. A stationary hook was installed in the back of the Crown Press opposite the front hook as shown in Figure 3.3. This hook is used to hold the rear of the top belt in place and to allow for even pulling of the belt. It is secured in place with a nut.
3. Six pins were inserted into the bottom rear lip of the crown and holes lining up with these pins were drilled into the press frame as shown in Figure 3.4. This was done to keep the crown straight during tests.

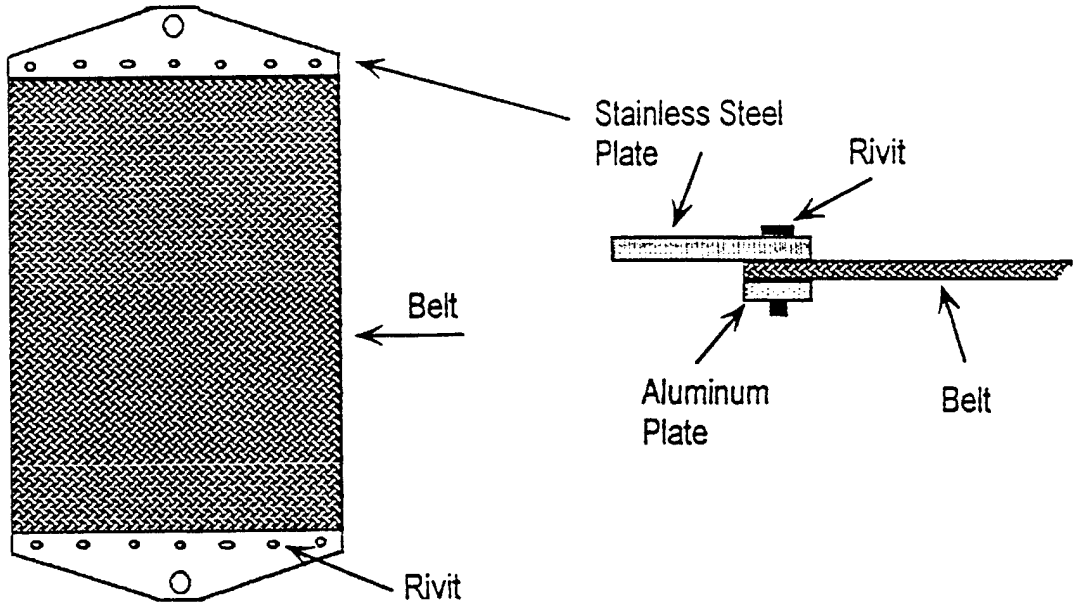


Figure 3.2 Crown Press belt design.

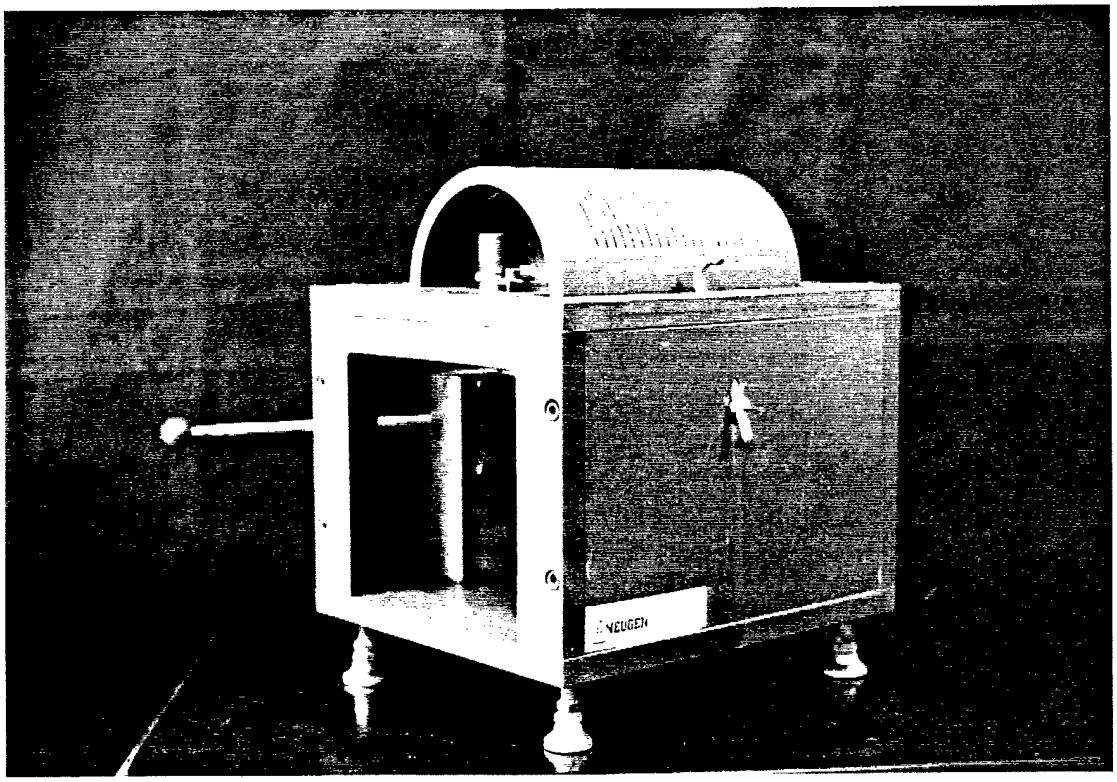


Figure 3.3 Crown Press hook modification.

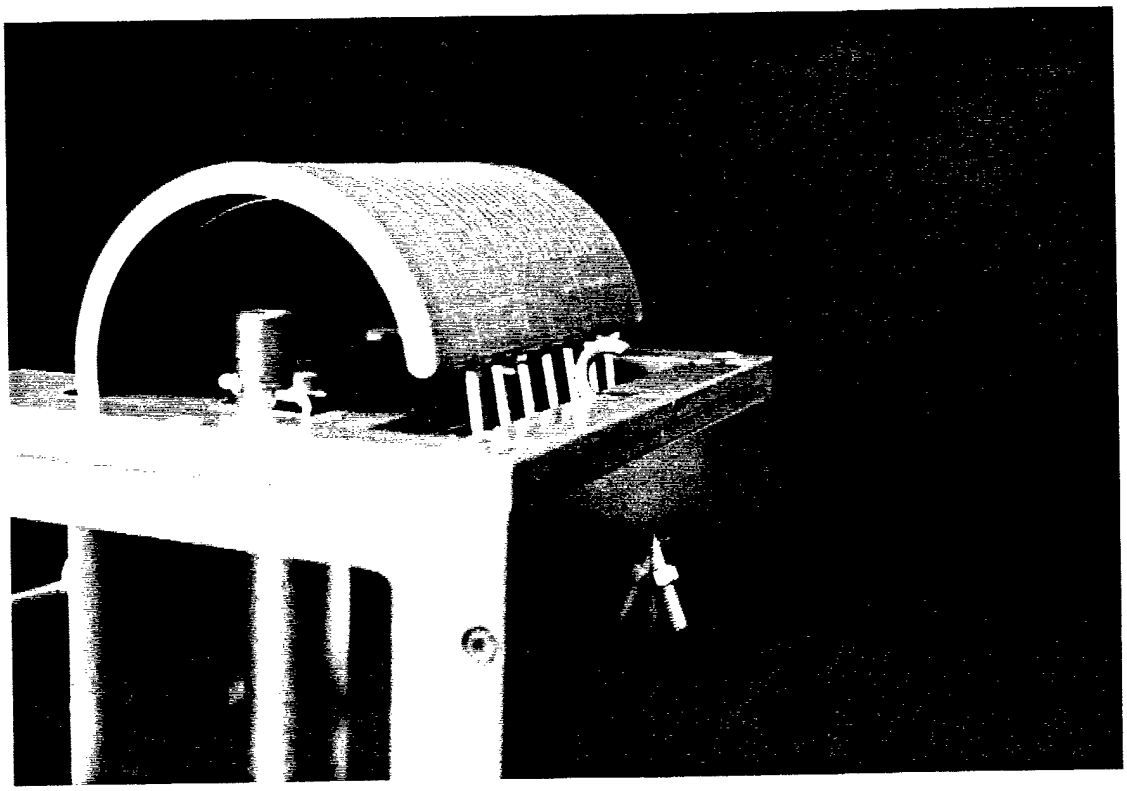


Figure 3.4 Pin modification of the Crown Press.

3.3.2 Crown Press Calibration

Calibration of the Crown Press was necessary to determine the accuracy of the Crown Press gauge reading (CPGR). A series of belt tensions was applied with a fish scale to the front of the top belt, and the subsequent CPGRs were recorded. A linear regression of CPGRs and a range of applied tensions has the following form:

$$Crown\,Press\;Gauge\;Reading(lb) = m * T_C + b, \tag{3.1}$$

where

m = the slope of the linear regression;
T_c = the belt tension on the crown in lb_f;
b = the y-intercept.

The calibration yielded the following equation relating CPGRs to true belt tensions:

$$CPGR(lb) = 0.7055T_C + 1.33. \tag{3.2}$$

Using the equations presented by Severin and Collins (1992) and by Galla (1996) which relate the pressure applied over a cylindrical surface to the tension applied, belt width and crown diameter, a relationship between the pressure and the CPGR was established by the following equation:

$$PSI = \frac{2 * (CPGR - b)}{m * W_C D_C}, \tag{3.3}$$

where

W_c= the width of the belt, 7 in.
D_c= the diameter of the crown, 6.5 in.

By combining Equations 3.2 and 3.3, the following equation expressing pressures in terms of the CPGR is obtained:

$$PSI = \frac{2*(CPGR-1.33)}{0.7055*W_C D_C} = \frac{CPGR-1.33}{16.05}. \quad (3.4)$$

After determining the pressures for the corresponding gauge readings, the Crown Press lineal belt tension was calculated by the equation:

$$T_l = PSI \times D, \quad (3.5)$$

where T_l is the lineal belt tension in (lb/in) and D is the diameter of the crown (6.5 in). This equation can be used because the load applied is distributed over the width of the belt, giving a lineal belt tension.

All Crown Press tests were conducted using CPGRs, which were then converted to pressures for all of the reported data. Table 3.1 shows a range of CPGRs and the corresponding pressures used in this project. Equation 3.4 and Equation 3.5 were used to obtain the pressures and lineal belt tensions related to each CPGR, respectively.

Table 3.1 Crown Press gauge reading to pressure conversions.

Crown Press Gauge Reading (lb)	Pressure Applied to Sludge (psi)[1]	Crown Press Lineal Belt Tension (lb/in)[2]
10	0.54	3.51
20	1.16	7.56
40	2.41	15.66
60	3.66	23.76
80	4.90	31.86

[1]Based on equation 3.4 [2]Based on equation 3.5

3.3.3 CST Device

The CST instrument used in the laboratory testing portion of this project was manufactured by Venture Innovations, Inc., in Lafayette, Louisiana. The device, shown in Figure 3.5, has three test heads allowing for three samples to be run at one time. The stainless steel cylinders, which hold the conditioned sludge sample in the test heads, have two different sized openings on either end, a 10-mm and an 18-mm inside-diameter opening. For all CST tests with conditioned sludge, the 10-mm diameter opening was used. Whatman No. 42 chromatography grade paper was used for CST filtration paper, which was obtained from Venture Innovations, Inc. pre-cut to fit the test head stands.

3.3.4 SRF Set-up

SRF tests were performed using the set-up shown in Figure 3.6. A 100 mL graduated cylinder was modified by adding a nipple to the top portion of the cylinder in order to attach a vacuum line and by molding the top neck so that a 9 cm Buchner funnel could be secured to the cylinder. The modified graduated cylinder was connected to a 250 mL flask reservoir. This reservoir prevented the introduction of any liquid into the lab vacuum system. A vacuum gauge was added to the vacuum flask, and the flask was attached to the lab vacuum system.

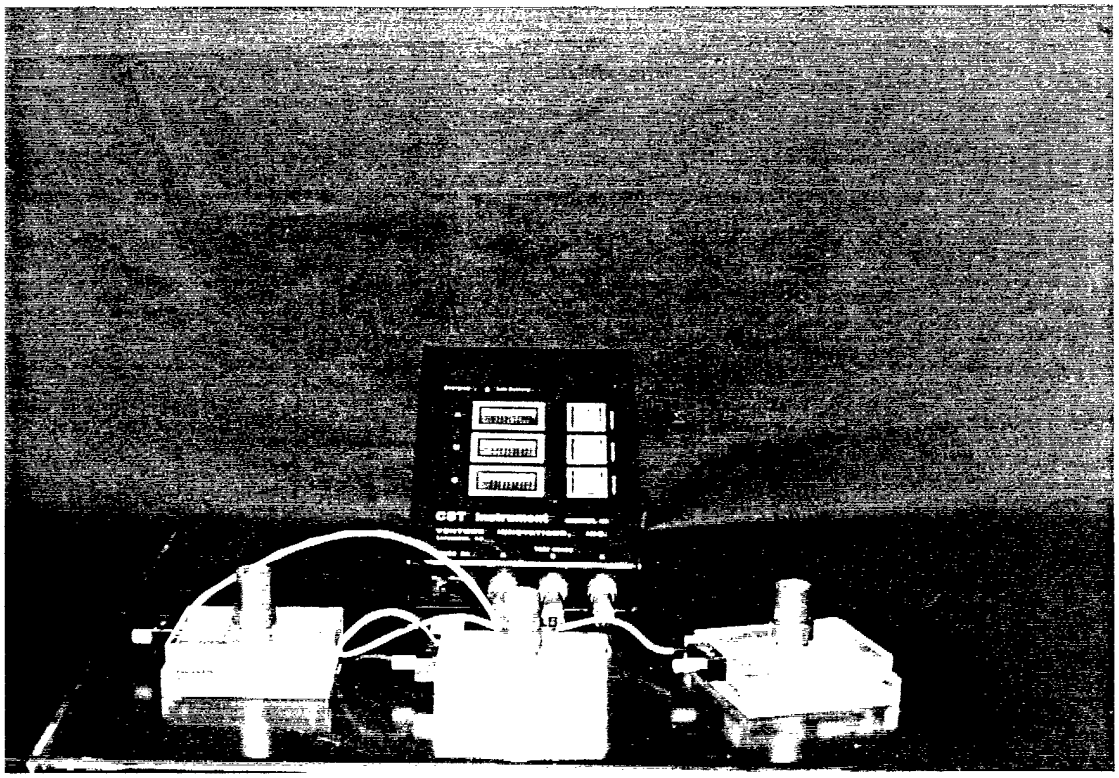


Figure 3.5 CST device.

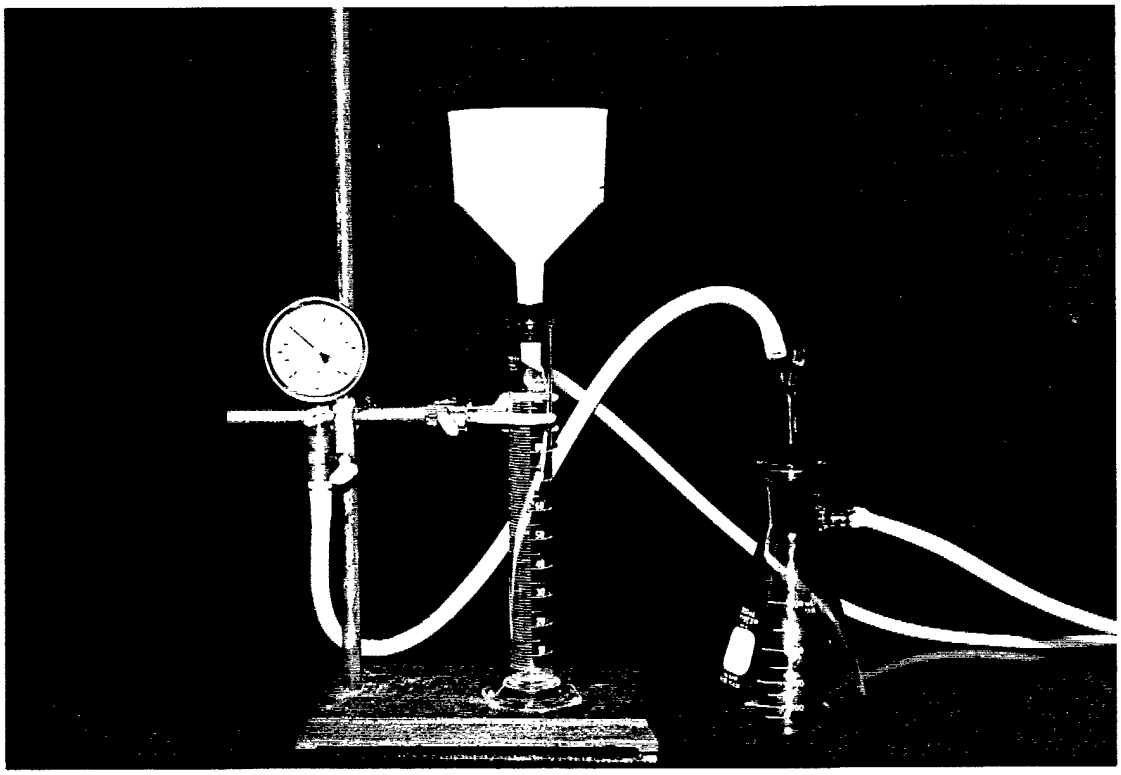


Figure 3.6 SRF test set-up.

3.4 Sludge

Based on the present needs of the Mauldin Road Facility to improve the dewatering capacity of the secondary BFPs, the WAS from the DAF tank was used in experimentation. Sludge for testing was collected primarily from two locations. For tests with lab conditioned sludge (LCS), the sludge was collected from the influent flow in the wet well (prior to polymer addition), and for tests with plant conditioned sludge (PCS), the sludge was collected immediately prior to discharge onto the gravity drainage zone. Because travel time from the treatment facility to the laboratory is less than one hour, preservation of the WAS was not necessary. Sludge that was not used for tests on the day it was collected was stored at 4°C.

3.5 Polymers

3.5.1 Types

Polymers used in the dewatering process come in four forms: dry powders, liquid solutions, liquid emulsions, and mannichs. Dry form polymers are provided in powder, granular (pellet), flake, or bead form. They are typically 90-100% active product, with 95% being a reasonable average for most applications with dry polymer. Liquid polymers are true solutions of polymer in water with a concentration ranging from 3-50% by weight. Because the liquid polymers used in the wastewater industry for sludge conditioning have high molecular weights, they are limited to 5-10% active product concentration. At concentrations higher than these, the polymer solution becomes too viscous for effective use. Liquid emulsion polymers appear as milky, disperse liquids and have an active product concentration ranging from 30-60%. The higher

concentrations are achieved through the additives used during production that produce a lower viscosity fluid than would normally exist in a water-based solution at an equal concentration. Mannich polymers are highly viscous, clear gels with active solids content on the order of 3-4% (Dentel et al., 1993).

Although the Mauldin Road facility is currently using dry polymer (Environmental Specialties 1598) in their facility, this study included dry, liquid and emulsion polymers for lab conditioning tests. Samples of various polymers from three distributors were collected. There are numerous polymer suppliers in the United States. Some of them include Allied Colloids Inc., Callaway Chemical, Diatec Environmental, Stockhausen, Inc., Cytec Industries, and Secondyne Inc. Often these polymer suppliers sell their product to distributors who then repackage the polymer to sell to treatment plants. The Mauldin Road facility purchases its polymer from Environmental Specialties (ES) who sells a wide variety of polymers, including products from Allied Colloids and Stockhausen. Most distributors can provide information about the polymer concentrations that are typically used for the different sludge types. This served as a starting point for determining polymer dosages with the sludge from WCRSA. Polymers used in this research are listed in Table 3.2.

Table 3.2 Polymers used in this project.

Polymer Name	Manufacturer	Polymer Type	Active Product (%)	Dilutions Used (g/L)
ES 1598/ Percol 787	Allied Colloids	Dry	95	0.40%
Superfloc SD 2081	Cytec	Emulsion	41	0.39-0.41%
Superfloc SD 2085	Cytec	Emulsion	41	0.38-0.40%
Superfloc C-496	Cytec	Dry	90	0.50%
Percol 775 FS25	Allied Colloids	Liquid Dispersion	50	0.50%
Percol 778 FS25	Allied Colloids	Liquid Dispersion	50	0.50%

3.5.2 Polymer Preparation

The preparation of polymer solutions used during lab testing was based on the polymer preparation methods used at the Mauldin Road facility and the information provided in the polymer preparation manual distributed by WEF (1993). The Mauldin Road facility uses an average polymer solution of 0.35% (3.5 g/L) to condition the secondary sludge. All lab polymer solutions were between 0.4% and 0.5% for lab conditioning tests. The polymer dilutions were mixed with 500 mL of tap water in a 1000 mL beaker using a Lightin® LabMaster™ SI Mixer at 400 rpm. In accordance with information from the *Guidance Manual for Polymer Selection in Wastewater Treatment Plants* (1993), the polymer dilutions were used within 5 days.

To prepare dry polymer dilutions, a mass of dry polymer that would produce a dilution between 0.4% and 0.5% was weighed in a plastic dish. The dry polymer was slowly sprinkled into a highly turbulent region of the tap water. The plastic dish was

weighed again and the difference between the initial and final weights was used to calculate the polymer added and therefore the resulting concentration. The polymer solution was mixed for 1 hour and allowed to age overnight. Prior to using the polymer on subsequent days, the dilution was mixed again for 20-30 minutes.

Liquid and emulsion polymer solutions were produced by injecting a volume of stock polymer using a 5 mL syringe into 500 mL of rapidly mixing tap water. Because the stock polymer solutions are too viscous to pass through a needle, the syringes were used without needles. The syringe was weighed with a given volume of stock polymer in it. After adding the stock polymer to the water, the empty syringe was weighed again. The difference between the initial and final weights was used to calculate the polymer added and therefore the resulting dilution. The solution was mixed until it was homogenous, which typically took less time than with the dry polymer solutions. The following formula was used to calculate the polymer dilution concentration:

$$Polymer\ Dilution\ Conc(g/L) = \frac{M_p f_p}{V_w} * 1000mL/L, \qquad (3.6)$$

where M_P is the mass of polymer added (g), f_p is the polymer active fraction (g polymer solids/g polymer), and V_w is the volume of water used (mL). A typical calculation is as follows: Assume 5 g of an emulsion polymer with an active content of 41% or 0.41 g/g is added to 500 mL of water. Using Equation 3.6, the calculated polymer dilution concentration is

$$Polymer\ Dilution\ Conc(g/L) = \frac{(5g)*(0.41)}{500mL} * 1000mL/L = 4.1g/L. \qquad (3.7)$$

Liquid and emulsion polymers were analyzed for active content according to the procedures provided in the *Guidance Manual for Polymer Selection in Wastewater Treatment Plants* (1993). A volume of the neat polymer solution was added to a methanol and acetone solution which precipitated the polymer as a white powder. The solution with precipitate was filtered and the filter paper was dried (105°C) for two hours to determine the mass of dry polymer. In all cases, the active content of a polymer according to the polymer manufacturer was the same as the polymer active content determined in the lab.

3.5.3 Polymer Dose Reporting

All polymer doses in this project are reported as pounds of dry polymer per dry ton of sludge (lb/ton). The following formula was used to calculate polymer dosage:

$$Crown\,Press\,Dose(lb/ton) = \frac{V_p D_p}{V_s \rho_s f_s * 10} * 2000 \frac{lb}{ton}, \tag{3.8}$$

where V_p is the volume of polymer solution used (mL), D_p is the polymer dilution (g/L) as calculated from Equation 3.6, V_s is the volume of sludge used (mL), ρ_s is the sludge density (g/L), and f_s is the sludge solids fraction (g sludge solids/g sludge). The density of the sludge was determined by weighing a known volume (1 mL) of sludge several times delivered from a syringe without a needle and averaging the results. A typical calculation is as follows: Assume a 300 mL sludge sample with a density of 980 g/L and solids content of 3.65%. The amount of polymer required is 16 mL at the dilution concentration calculated in the above example of 4.1 g/L.

Using Equation 3.8 and the given values, the calculated polymer dose is

$$Dose(lb/ton) = \frac{(16mL)*(4.1g/L)*2000lb/ton}{(300mL)*(.98g/mL)*(3.65)*10} = 12.2\frac{lb}{ton}. \quad (3.9)$$

3.6 Single Press Test

There are four variables on the Crown Press that should be the same as on a BFP in order to achieve an accurate simulation: belt fabric, polymer type, polymer dose, and the Crown Press pressing regime. The pressing regime is the most difficult to reproduce on the Crown Press because it is dependent on the BFP belt speed and belt tension. The belt tension of the BFP is difficult to determine in the absence of graphical conversion charts. This is the case for the Eimco secondary BFPs used at the Mauldin Road WWTP. Because the accuracy of the pressure gauges for the hydraulic cylinders is uncertain, the accuracy of the corresponding belt lineal tensions is also uncertain. Thus choosing a belt tension on the Crown Press that is representative of the BFP may not be possible. To eliminate this problem, Galla (1996) developed the single press test so that site specific dewaterability could be evaluated without determining the actual BFP belt tension. Galla showed that the single press test was effective at producing final percent cake solids that were within the range expected for a BFP (Galla, 1996).

The single press test is performed by pressing multiple sludge samples over a range of pressures and times under pressure (see section 2.4.4). A plot of the final percent cake solids as a function of pressure and time can then be used to establish the expected performance of a BFP. This series of single press tests eliminates the need for a BFP pressing regime to evaluate the dewatering capabilities of a BFP (Galla, 1996). This

research utilized the procedure of the single press test to estimate the operating performance of the BFPs with variations in the three previously listed variables.

3.6.1 Plant Conditioned Sludge Tests

PCS was obtained from the front of the gravity drainage section of the BFP, just after it had been mixed with polymer. This conditioned sludge was well flocculated at the time of collection. For some PCS tests, the pressing was done at the plant site immediately after collecting a volume of conditioned sludge. In other cases, the PCS was collected in 1-gallon jugs and transported back to the lab for testing. If any of the PCS was not used in the lab on the day it was collected, the sample was stored at 4°C until it was used. In most cases the PCS was used within 48 hours of being collected. For all PCS tests, the belt material used on the Crown Press was the same as the belt material on the presses at the time of this project.

The PCS testing involved the following steps:

1. A volume of sludge was collected as the sludge fell from the hopper onto the gravity drainage section.
2. An aliquot of sludge (typically 300 mL) was gravity drained for a length of time equivalent to the time of gravity drainage on the BFP. This was done on a piece of belt fabric identical to that used on the BFP. The sludge was plowed with a plastic scoop to simulate the plowing that occurs during drainage. The gravity zone of the Eimco presses is 13 feet long, and the belt speeds for the presses range from 22-25 ft/min. This provides 30-35 seconds of gravity drainage. The same length of time was used prior to Crown Press testing.

3. The gravity drained sludge was then transferred to the bottom half of a petri dish in order to form a circular patty of 3.5" diameter and 0.625" thick.

4. The petri dish was inverted onto the bottom belt of the Crown Press to transfer the sludge patty.

5. The second belt was placed over the bottom belt with the sludge patty in between.

6. A predetermined pressure was then applied for a given length of time ranging from 10 to 90 seconds.

7. For PCS tests performed in the lab, skip to step 9. For PCS tests performed at the plant site, the sludge cake was stored in a sealable plastic storage bag. This retained any of the moisture that evaporated from the sludge cake before drying.

8. The sludge cake was transported to the laboratory. Before weighing and drying, the sludge was mixed with whatever moisture that was released from the cake and captured in the plastic bag.

9. The sludge cake was divided into three portions in aluminum weighing dishes, weighed, and dried at 105° C for 24 hours to determine the percent solids.

This process was repeated at the same pressure for increasing lengths of time, up to a maximum of 90 s. This maximum time under pressure was based on the lowest reasonable speed that the BFPs could operate without a significant decrease in loading, which is around 8-9 ft/min. Then, the pressure applied on the sludge was increased for each length of time being tested. The highest pressure tested was that which kept the belt from blinding significantly. Unless otherwise noted, the belt material used on the Crown Press was identical to the belt material used on the BFP.

3.6.2 Lab Conditioned Sludge Tests

LCS tests used sludge obtained from the wet well of the belt press facility. This influent sludge had an average solids content of 3.5%. These tests were performed in a manner similar to PCS testing with respect to the actual pressing sequence. The main difference between LCS and PCS tests was the sludge conditioning, which was done on a much smaller scale in the lab. The first LCS tests used the polymer ES 1598 for conditioning, which is the dry polymer currently being used at the Mauldin Road facility. After becoming comfortable with the conditioning step using ES 1598, the five other polymers listed in section 3.5.1 were used for conditioning.

The LCS testing involved the following steps:

1. A polymer solution between 0.35-0.50% was prepared as described in section 3.5.2.
2. 300 mL of influent sludge was added to a 500 mL square plastic container.
3. Increasing volumes of the polymer solution ranging from 6 to 24 mL were added to 300 mL of influent sludge using a syringe. Based on the average polymer dosage of 10-14 lb/ton used at the Mauldin Road facility, the initial polymer volume added was one that gave a dose in this range.
4. The sludge/polymer combination was mixed for 15 seconds at 400 rpm using the Lightin® LabMaster™ SI Mixer. If floc particles did not form with the first polymer volume, it indicated the polymer dose was too low. If floc particles formed with the first polymer dose tested, then the polymer dose was decreased until floc formation did not occur.
5. The polymer volume was then increased above this lower limit by 2 mL with a fresh 300 mL of influent sludge. This was continued until the sludge flocculated and clear,

free water was present, indicating the lowest dose that allowed for good floc formation.

6. The polymer volume was increased again until the sludge flocculated poorly, indicating a polymer overdose.

7. Each conditioned sludge sample was tested using CST and SRF, as described in section 3.7.

3.7 Capillary Suction Time and Specific Resistance to Filtration Tests

SRF and CST tests are extensively used and widely accepted in the wastewater treatment industry as a means for measuring potential dewaterability and sludge conditioning. These tests were performed along with Crown Press tests using LCS. The CST test was performed according to procedures in *Standard Methods* (1992), section 2710 G. Between 7 and 8 mL of conditioned sludge was added to the test reservoir using a 10-mL syringe. The tip of the syringe was cut off in order to allow free passage of sludge flocs. The CST for each conditioned sludge sample was measured a minimum of three times.

SRF was performed according to procedures in *Standard Methods* (1992), section 2710 H with modifications as presented by Galla (1996). A 9-cm diameter Whatman No.1 filter paper was seated in the Buchner funnel with deionized water. The vacuum was turned on to remove excess moisture from the filter paper, and this moisture was discarded. The vacuum was turned on again, and between 100 and 150 mL of sludge was added to the Buchner funnel depending on the conditioning state of the sludge. As soon as the sludge was added, a stopwatch was started. The time for every 5 mL of filtrate to collect in the graduated cylinder was recorded, up to 100 mL of filtrate. The filtrate data

was plotted with t/V versus V, where t is time in minutes and V is filtrate volume in milliliters. The slope of the linear portion of the beginning of the plot was calculated, as shown in Figure 3.7. The slope was then used in Equation 3.10 to calculate the SRF.

$$r = \frac{2PA^2}{\mu_f c} b, \tag{3.10}$$

where P is the vacuum pressure in dynes/cm^2, A is the filter paper area in cm^2, μ_f is the filtrate viscosity in poise, c is the solids fraction of the unconditioned sludge in g/cm^3, and b is the slope of the regression line in s/cm^6. Using these units, SRF has units of cm/g. Typically, μ_f is assumed to equal the viscosity of water or a constant value of 0.011 poise [g/(s*cm)] (Christensen et al., 1993). The solids fraction, c, was calculated using the equation

$$c = \frac{C_k C_o}{100 * (C_k - C_o)}, \tag{3.11}$$

where C_o is the percent solids in the feed sludge and C_k is the concentration of the cake solids (Karr and Keinath, 1978).

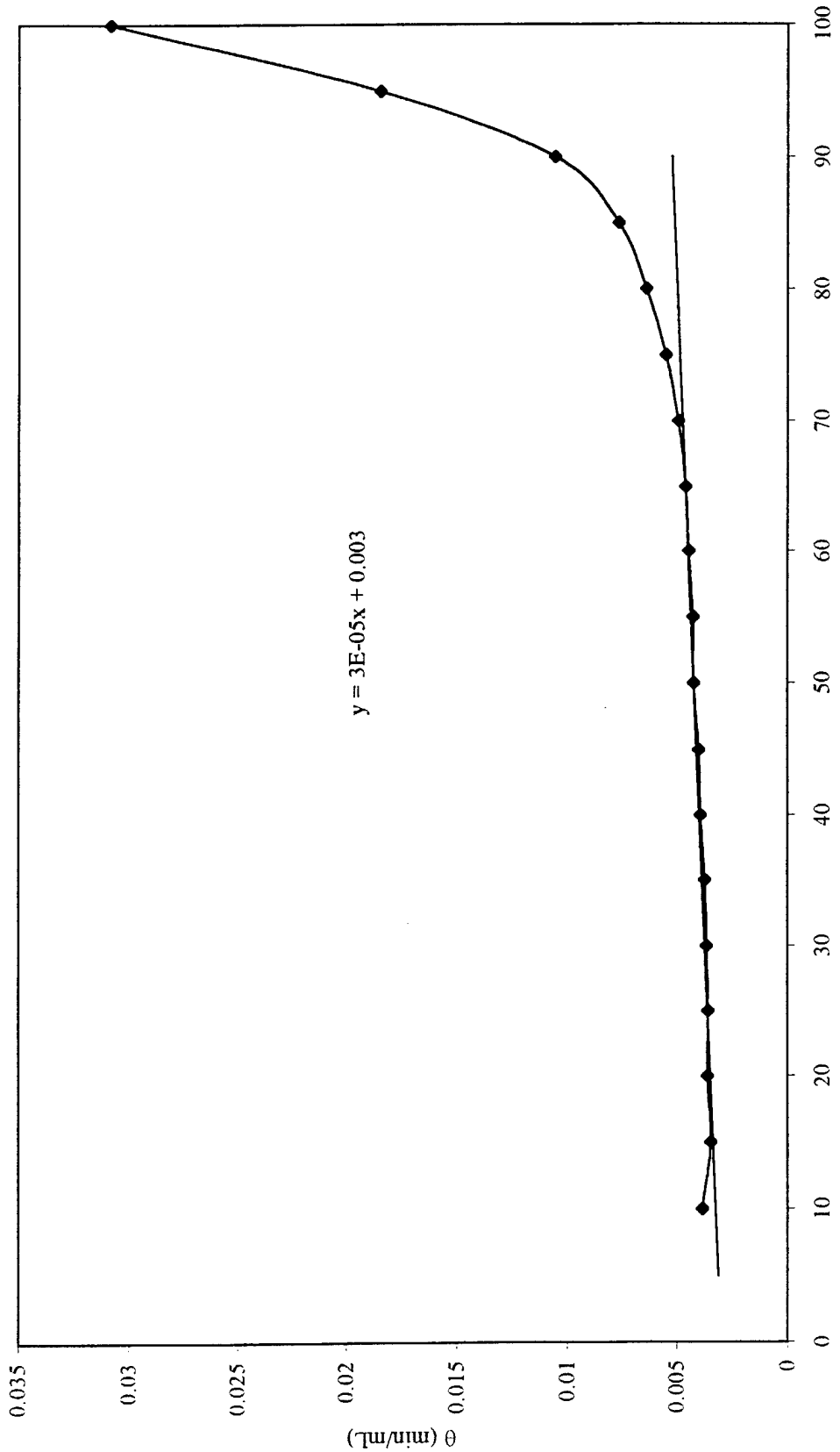


Figure 3.7 SRF example plot with regression for Percol 778 FS25 at a dose of 15.8 lb/ton

3.8 Lab Polymer Testing

The results from the CST and SRF tests for each polymer were plotted versus polymer dose. Using these plots, 3 to 4 polymer dosages for each polymer were chosen for testing with the single press test on the Crown Press. The first dosage chosen was that which produced the minimum CST and SRF value. The other dosages were usually within 5-7 lb/ton of the first dosage. Each polymer dose was tested on the Crown Press with belt material identical to that on the BFP, according to the procedures outlined in section 3.6.1 for PCS testing starting with step 2. If the initial polymer dose did not produce a pressable sludge on the initial test, the next higher dose was tested. Sludge was considered non-pressable if it ran off the crown. This continued until a pressable sludge resulted. In most cases, the initial polymer dose was pressable on the Crown Press. For each polymer dose tested, the pressure and time under pressure were increased until significant belt blinding occurred. Determining when a belt was blinding was somewhat subjective. However, after many press-tests over a range of pressures, visually detecting blinding became easier. Belt blinding is discussed further in Chapter 4.

As previously discussed in section 3.2, the BFPs at the Mauldin Road facility are currently operating at the upper limit for hydraulic pressure. Because of this, using the Crown Press to find a polymer that would allow the use of higher belt tensions without blinding was not a top priority of this research. Rather, this research focused on finding a polymer that would provide one of two advantages under the current operating parameters. The first advantage would be to produce a final cake similar to that being obtained now using a less expensive polymer. The second advantage would be to produce a final cake that is considerably higher in cake solids concentration than the

current average final cake, such that a potential increase in polymer cost would be out-weighed by a decrease in kiln dust used for stabilization.

3.9 Lab Belt Tests

Samples of several different types of belt material were obtained from two filter belt manufacturers, Industrial Fabrics (IF) Inc. and a company that requested that its name not be published (referred to as Company X). These belts had varying air permeability coefficients, thread counts, thread weight and weave characteristics. The secondary BFPs at the Mauldin Road facility use filter belts purchased from Eimco. The product code for this material is DA9148. Eimco purchases the belt material from companies like IF, which relabels the belt material and then sells it to consumers. Eimco was contacted in an attempt to cross-reference the product they sold to the Mauldin Road facility with samples from the other manufactures. This proved to be unsuccessful. Personnel at Eimco were unwilling to release either the belt material characteristics or the company from which it purchased the Mauldin Road belt material. To ensure that the belt material used during PCS, LCS, and polymer tests was the same as the material on the BFP, a portion of an old belt that had been used on one of the BFPs was cleaned and brought back to the lab. With some guidance from a technical sales representative at IF, the sample from the old belt was visually compared to several of the IF samples. The BFP belt most closely matched IF belt number 6927.

To compare the performance of the BFP belt material to other belt material, two belt samples from IF and two from Company X where prepared as described in section 3.3.1 for use on the Crown Press. LCS tests were conducted with polymer ES 1598 at

10.1 lb/ton. The conditioned sludge was pressed with the four different belt samples and the BFP belt material at 1.16 and 2.41 psi for 15, 30, 45, and 60 seconds.

3.10 Solids Capture Tests

During tests with the Crown Press it is also possible to measure solids capture efficiency. This was done by collecting pressate and belt wash water from the single press tests. During the press test, pressate collects in a channel on top of the base of the Crown Press (Figure 3.8). This pressate flows by gravity to a low point in the channel and drops through a plastic tube into a beaker. After the press test, the pressate catch channel was rinsed with deionized water and collected in the beaker. The volume of collected pressate was measured with a graduated cylinder and stored in a plastic container. The top and bottom belts were washed using a high-pressure spray, analogous to what is done on a BFP. The wash water was collected in a plastic tub. Prior to using the tub, water was added to the tub in 1-liter increments. The water level at each volume was marked on the outside of the tub, up to 7 liters. This provided graduations for measuring the volume of water used during belt washing. After recording the volume of wash water used to clean the belts in the tub, the water was well mixed by hand and an aliquot of wash water was collected in a plastic container.

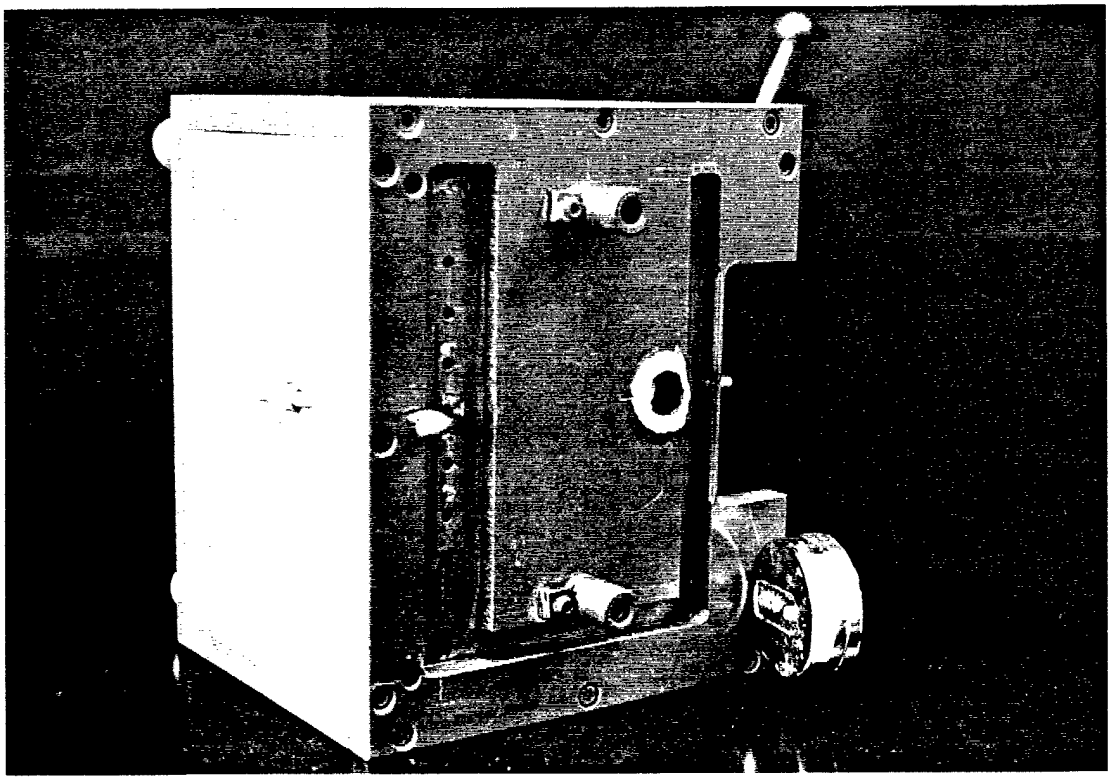


Figure 3.8 Top of the Crown Press with channel for collecting pressate.

Both samples were stored at 4°C until they were tested for suspended solids concentration, according to procedures in *Standard Methods* Sections 2540 D (1992). Using these TSS values and the dewatered cake solids, the capture efficiency was calculated as follows:

$$CaptureEfficiecny(\%) = \frac{A}{A+B+C} * 100, \qquad (3.12)$$

where A is the mass of solids in the dewatered cake (sum of three samples); B is the mass of total suspended solids (TSS) in the filtrate collected directly off the Crown Press (volume*concentration); and C is the mass of TSS from washing the belts (volume*concentration).

3.11 Metals Testing

Following the laboratory polymer tests, the effect of divalent cations on the dewaterability of Mauldin Road's WAS was investigated. Higgins and Novak (1996) presented three guidelines for improved dewaterability in activated sludge systems based on the presence of monovalent and divalent cations in the mixed liquor: 1) the minimum concentration of Ca^{2+} and Mg^{2+} in the mixed liquor should be 0.7 – 2.0 meq/L; 2) the monovalent to divalent ratio (specifically Na^{+} and K^{+} to Ca^{2+} and Mg^{2+}) should be less than 2:1; and 3) Ca^{2+} and Mg^{2+} should be present in equimolar ratios for effective dewatering in some activated sludge systems (Higgins and Novak, 1996). To conduct these tests, operating data from the Mauldin Road plant was collected. The concentrations and ratios presented by Higgins and Novak (1996) were based on metals measurements of the mixed liquor at the plants used in their study. Unfortunately, the mixed liquor at the Mauldin Road facility is not sampled for metals. Therefore, there was no historical metals data that could be used to determine the concentrations of the monovalent and divalent cations. However, the plant does measure the concentration of metals in its influent and effluent twice a week. It was decided to use the metals data from the effluent samples because the chemical composition of the WAS should be the same as the chemical composition of the secondary effluent. To test this assumption, the BFP operators collected filtrate samples from all four presses several times during the months of February and March 1998, which were also tested for metals composition. These samples were used to determine if there was a significant difference in the metals composition of the secondary effluent and the liquid portion of the sludge. Table 3.3

summarizes the data collected on the metals concentrations for both secondary effluent and BFP filtrate.

Table 3.3 Metals concentrations for Mauldin Road facility.[1]

	Mg^{2+} Conc. (meq/L)	Ca^{2+} Conc. (meq/L)	K^{+} Conc. (meq/L)	Na^{+} Conc. (meq/L)	Ca/Mg	Mono-/ Divalent
Secondary Effluent	0.08 ± 0.02	0.45 ± 0.06	0.50 ± 0.74	6.3 ± 1.4	5.9 ± 1.1	12.9 ± 3.6
BFP Filtrate	0.28 ± 0.03	0.92 ± 0.11	0.59 ± 0.13	5.6 ± 1.6	3.2 ± 0.4	5.3 ± 1.5

[1] ± values represent one standard deviation

Although the metals concentrations were different and the monovalent/divalent ratio in the BFP filtrate was lower than in the secondary effluent, both sets of data indicated that Mg^{2+} and Ca^{2+} were deficient in the BFP filtrate.

To test the potential affect of divalent cations on the dewaterability of WAS, 2.5 meq/L of Ca^{2+} and Mg^{2+}, in the forms of $CaCl_2$ and $MgCl_2$, initially were added to 1-L of unconditioned sludge with a solids concentration of 3.18% (31,800 mg/L). This equated to roughly 0.08 meq/(g of solids) for both Ca^{2+} and Mg^{2+}. According to Higgins (1998) the mixed liquor used in their study had concentrations ranging from 1500 to 3000 mg/L. Using the high ends of the minimum metals concentrations required for effective dewatering and of the mixed liquor concentrations, their studies indicated a mass concentration of 0.67 meq/(g of solids) for both Ca^{2+} and Mg^{2+}. Needless to say, the 2.5 meq/L of Ca^{2+} and Mg^{2+} initially added in this study had no impact on the WAS. To compensate for the fact that the WAS used in these tests was much more concentrated than the mixed liquor used in the study by Higgins and Novak (1996), the amounts of Ca^{2+} and Mg^{2+} added to the sludge were increased to mass concentrations of 0.80 and

0.79 meq/(g of solids), respectively. This resulted in approximately a ten-fold increase in concentration for both divalent metals (from approximately 2.5 meq/L to 25 meq/L).

After adding the divalent metals to the WAS, the sludge was conditioned with an ES 1598 dilution of 0.47% at three polymer doses for CST and SRF testing. These tests were conducted side-by-side with identically conditioned WAS that was not enhanced with divalent cations. Following the CST and SRF tests, two polymer doses were tested on the Crown Press using metal-enhanced sludge and normal WAS.

3.12 Plant Testing

After completing various stages of laboratory testing, two polymers were selected for testing on the BFPs, along with the currently used polymer (ES 1598). These tests were used to compare the results obtained in the lab with the Crown Press. The two BFP tests involved lowering the belt speed and changing the polymer. Each BFP test was compared to a BFP operating under normal conditions with the ES 1598 polymer.

3.12.1 Belt Speed Tests

On the BFP, changing the belt speed is equivalent to changing the time under pressure in the lab. The higher the belt speed the shorter the sludge is under pressure and vice versa. Laboratory tests showed that as the time under pressure increased for a given pressure, the final cake solids increased. To test this prediction, the belt speed on press 4 was decreased. Initially, when the speed was decreased, the solids loading to the belt was not adjusted. This caused the height of the rows of sludge to increase significantly producing a loading condition that was not identical to the higher speed operation. Thus, the final cake solids produced at the lower belt speed could not be directly compared to

the final cake solids produced at the higher speed. In order to compare final cake solids at different speeds, a solids loading factor based on the speed of the belt was determined. This factor was a ratio of solids loading in pounds of dry solids per hour to belt speed in feet per min. The following is an example calculation using this ratio: Assume the BFP is being loaded at a rate of 1400 lb/hr, and the belt speed is 22.5 ft/min, then the loading factor is:

$$Loading\ Factor = \frac{1400 lb/hr}{22.5 ft/\min * 60 \min/hr} = 1.04 lb/ft. \quad (3.13)$$

Prior to decreasing the belt speed, the loading factor was calculated using the initial values for solids loading and belt speed. The decreased belt speed was then used to calculate a new loading factor. For example, assuming the initial operating conditions as presented above (Equation 3.13) and a belt speed of 12.5 ft/min, then the new solids loading rate needed to maintain the same loading factor is:

$$Solids\ Loading(lb/hr) = (12.5\frac{ft}{min})(60\frac{min}{hr})(1.04\frac{lb}{ft}) = 780 lb/hr. \quad (3.14)$$

For each belt speed tested, the corresponding solids loading rate was determined in order to maintain operational consistency between the different conditions.

3.12.2 Polymer Tests

Results from the lab polymer testing described in section 3.8 were used to choose two polymers to test on the BFPs. The first polymer selected was Allied Colloid's Percol 775 FS25. The second polymer tested was Cytec's Superfloc SD 2085. During the two

weeks that these polymers were tested on the BFPs, equipment failure prevented testing on all four presses. Press #2 was not operated during the tests with Percol 775 FS25 due to a pump motor malfunction. At the end of testing with Percol 775 FS25, the drive shaft on press #1 malfunctioned, eliminating it from the Superfloc SD 2085 testing. In addition to these problems, the operators were having difficulties keeping the sludge pump for press #4 in operation. Press #4 was included in all Percol 775 FS25 testing, but was not included in Superfloc SD 2085 testing due to this problem. Table 3.4 summarizes the operating schedule for the two weeks of plant testing.

Table 3.4 Operating schedule for plant polymer testing.

Date	Press #1	Press #2	Press #3	Press #4
March 23, 1998	Prepared Percol 775 FS25 for testing			
	ES 1598, 12.5 lb/ton Number of Samples: 7	Not Operating	ES 1598, 17.1 lb/ton Number of Samples: 12	ES 1598, 13.2 lb/ton Number of Samples: 12
March 24	Percol 775 FS25, 14.6 lb/ton Number of Samples: 3	Not Operating	ES 1598, 17.6 lb/ton Number of Samples: 9	ES 1598, 11.6 lb/ton Number of Samples: 9
March 25	ES 1598, 8.7 lb/ton Number of Samples: 6	Not Operating	Percol 775 FS25, 17.0 lb/ton Number of Samples: 10	Percol 775 FS25, 12.9 lb/ton Number of Samples: 10
March 30	Not Operating	Percol 775 FS25, 24.1 lb/ton Number of Samples: 10	ES 1598, 12.1 lb/ton Number of Samples: 10	Not Operating
March 31	Prepared Superfloc SD 2085 for testing			
April 1	Not Operating	SD 2085, 14.2 lb/ton Number of Samples: 12	ES 1598, 16.3 lb/ton Number of Samples: 12	Not Operating
April 2	Not Operating	ES 1598, 9.9 lb/ton Number of Samples: 7	SD 2085, 16.5 lb/ton Number of Samples: 7	SD 2085, 17.0 lb/ton Number of Samples: 7
April 3	Not Operating	SD 2085, 20.9 lb/ton Number of Samples: 8	ES 1598, 10.1 lb/ton Number of Samples: 8	Not Operating

Representatives from ES, who supplied the Percol 775 FS25, and Cytec were contacted for advice on proper mixing and dosing procedures and were onsite during the days their polymer was tested. These polymers were mixed in two 31000-gallon tanks that were originally used for mixing polymer for the DAF tanks. The polymers were added to the mixing tanks using a 2-gallon bucket. Prior to the start of this experiment, the piping from these two polymer mixing tanks was connected to the BFPs. This allowed one polymer to be used on presses #1 and #2, while using a different polymer on presses #3 and #4.

On the day prior to starting BFP tests with Percol 775 FS5, samples of final cakes and pressate were taken on presses #1, #3 and #4 every half hour for the entire length of operation. These samples provided information on potential hourly variations in sludge characteristics and were used to compare the data collected during the polymer tests. The testing protocol for Percol 775 FS25 and Superfloc SD 2085 are provided in Table 3.4.

All of the final cake and pressate samples were stored in Glad-Lock® Zipper™ Sandwich Bags for transportation to the laboratory. Each final cake sample was divided into 3 aluminum weighing boats and dried for 24 hours at 105°C. The pressate samples were refrigerated at 4°C until they were tested for TSS.

CHAPTER 4

RESULTS

Data from the various laboratory and plant tests are presented in this chapter. These tests were performed as described in Chapter 3 (Materials and Methods). First, the precision of the single press test and capture efficiency test is presented. Following the precision analysis is a comparison of BFP cake solids as determined using microwave analysis versus *Standard Methods* oven analysis. Next, the concept of belt blinding as it relates to testing on the Crown Press is more clearly defined. Then, the results from PCS tests conducted from May to July 1997 are presented, along with BFP operating data from these same months. After conducting the PCS tests, several polymers were evaluated using CST, SRF, and the Crown Press. The results from these evaluations are provided according to the polymer tested.

Another operating parameter investigated in the laboratory testing portion of this project was belt fabric. The results of a side-by-side comparison between the belt fabric currently used on the BFPs at the Mauldin Road facility and four other belt fabrics are included. The final laboratory testing involved a small-scale study of the potential effects of added cations on the dewaterability of the WAS collected from the Mauldin Road facility. These tests were based on the work of Higgins and Novak (1996) who investigated the affects of cation concentration on the dewaterability of several types of sludges, as measured by CST. Following all of the laboratory data, the data from the full-scale tests is provided.

During the course of this project, several wastewater treatment plants were contacted that were reported to be using BFPs to dewater WAS. Those plants that were found to be dewatering undigested WAS sludge were asked several questions about the operating parameters of their plant and of their BFP operation. A summary of this survey is listed at the end of the chapter.

4.1 Evaluation of Precision

In order to evaluate the potential variability in sludge conditioning and Crown Press operation, a series of press tests were performed in triplicate. An influent sludge sample of 600 mL was conditioned at 18.28 lb/ton with Cytec's Superfloc SD 2085. This conditioned sludge was gravity drained and divided into four samples. The samples were pressed at 1.16, 2.41, 3.66, and 4.90 psi respectively for 30 seconds using Mauldin Road belt material. After pressing, each individual sample was divided into three separate samples, weighed, and dried for 24 hours at 105°C. The pressate and belt wash water were collected after each press test. These samples were tested for TSS as described in Chapter 3. Table 4.1 shows the results of these triplicate tests. The precision of these results should be representative of the results presented throughout this report. The coefficient of variation was calculated using the following equation:

$$Coefficient\ of\ Variation(\%) = \frac{Standard\ Deviation}{Average} \times 100\%. \qquad (4.1)$$

The precision of the trial cake measurements was high, as indicated by coefficient of variations consistently below 2%. The precision of the capture efficiency measurements was similarly high. Based on these results, it was concluded that single

trials on the Crown Press are adequate for describing Crown Press performance in terms of final cake solids and solids capture efficiency.

Table 4.1 Single press test and capture efficiency precision analysis.

	Final Cake Solids (%)*					
Press Pressure (psi)	**Trial #1**	**Trial #2**	**Trial #3**	**Average**	**Standard Deviation**	**Coefficient of Variation (%)**
1.16	13.12	13.49	13.27	13.29	0.19	1.41
2.41	13.62	14.10	13.66	13.79	0.27	1.96
3.66	14.93	15.10	14.73	14.92	0.19	1.25
4.90	15.21	15.43	15.08	15.24	0.18	1.17
	Capture Efficiency (%)					
1.16	97.57	95.92	97.29	96.93	.88	.91
2.41	90.24	90.16	90.05	90.15	.10	.11
3.66	79.38	78.87	82.30	80.18	1.85	2.31
4.90	77.75	77.49	75.98	77.07	.95	1.24

*Average of three measurements.

4.2 Solids Analysis

During the plant testing, several final cake samples from various tests were split and analyzed for solids content using the microwave technique at the BFP facility and oven analysis in the laboratory. The microwave technique dries a cake sample for five and a half minutes and automatically weighs and determines the solids concentration. It was suspected that the microwave method overestimated the concentration of the cake solids. These split samples were used to test this hypothesis. Table 4.2 shows the results of cake samples that were analyzed for solids concentration using both techniques. All of the samples were taken from presses #2 and #4. With the exception of one sample, all of the cake solids determined using the microwave were higher than the cake solids determined using oven drying. The average difference was 1.2% solids and the largest

difference was 2.8% solids. Using a paired difference t-test with α=0.05, it was determined that there is a statistically significant difference between the microwave and oven analyzed cake solids. These results supported the initial concern that microwave analysis did not thoroughly dry the cakes.

Table 4.2 Cake solids determined using oven and microwave analyses.

Sample #	Oven Cake Solids(%)	Microwave Cake Solids (%)	Difference
1-2	13.07	14.43	1.36
1-3	13.36	14.41	1.05
1-5	14.35	14.94	0.59
1-6	14.24	14.24	0
1-9	13.16	14.24	1.08
1-11	13.28	14.52	1.24
3-1	13.02	14.76	1.74
2-1a	12.88	15.22	2.34
2-1b	11.93	14.73	2.80
2-2a	14.63	15.38	0.75
2-2b	12.76	13.97	1.21
2-3a	14.54	15.08	0.54
2-3b	13.05	14.46	1.41
		Average:	1.24
		Standard Deviation:	0.75

4.3 Belt Blinding

Belt blinding on a BFP occurs when the polymer and solids block the drainage of filtrate away from the sludge cake. This can occur when either the sludge is overdosed with polymer or when the pressure in the shear zone of the BFP is too high. In the first case the excess polymer causes the sludge to stick to the belts and clog the weave. When the pressure is too high in the shear zone for the given polymer dose, the sludge is forced

through the weave. In either case, the in-line belt washing process typically cannot remove enough of the sludge and/or polymer to allow proper gravity drainage of the filtrate.

On the Crown Press, it is more difficult to determine the point at which the belts are blinded. Because there is not a strict definition of blinding or a uniform way to quantify its effect on the belts, visual inspection is the only means to differentiate between belts that are blinded and those that are not. Galla et al. (1996) defined blinding on the Crown Press as the point of failure for press tests. Unfortunately, this definition still leaves much room for interpretation.

To more clearly define this phenomenon on the Crown Press, a series of press tests was performed with increasing pressures. The sludge was conditioned with SD 2085 at 17.7 lb/ton and pressed at 1.16, 2.41 and 4.90 psi for 30 seconds. Figure 4.1a-d shows the progression of solids build-up on the belts. Figure 4.1a shows the clean belt before the press tests. The following three figures show the belts after a press test at each pressure. As the pressure increased, the amount of solids remaining on the belt after the sludge cake was removed increased. The highest pressure, 4.90 psi, resulted in belts that were blinded. Table 4.3 presents the cake solids (oven analyzed) and the capture efficiencies for these three press tests. Figure 4.1b shows that at 1.16 psi, a small amount of solids remained on the belt. This is reinforced by a capture efficiency of 98.6% and the mass of solids in the belt for this press test. In this figure the footprint of the cake is not distinguishable. At 2.41 psi (Figure 4.1c), the outline of the cake is clearer, but the solids on the outer edges are relatively sparse. There are still areas on the belt where the sludge cake did not leave solids in the weave. The capture efficiency for this test

decreased to 96.5% and the mass of solids in the belt increased to 0.14 g. Figure 4.1d shows the belt at a point of blinding. The footprint of the cake is very clear, and there are many areas on the belt in which the solids are so dense that the weave of the belt cannot be distinguished. The mass of solids on the belt was significantly higher than the two other tests, resulting in a lower capture efficiency of 84.5%.

Table 4.3 Press test results for belt blinding analysis.

Pressure (psi)	Cake Solids (Oven Analyzed)	Mass of Solids on Belt (g)	Capture Efficiency
1.16	13.32 ± 0.68	0.05	98.6%
2.41	13.96 ± 0.77	0.14	96.5%
4.90	15.35 ± 0.32	0.66	84.5%

Although the point of blinding still must be determined visually, these figures and data demonstrate that the observations made about the quality of the belt after a press test are supported quantitatively in terms of the mass of solids on the belt and the capture efficiency.

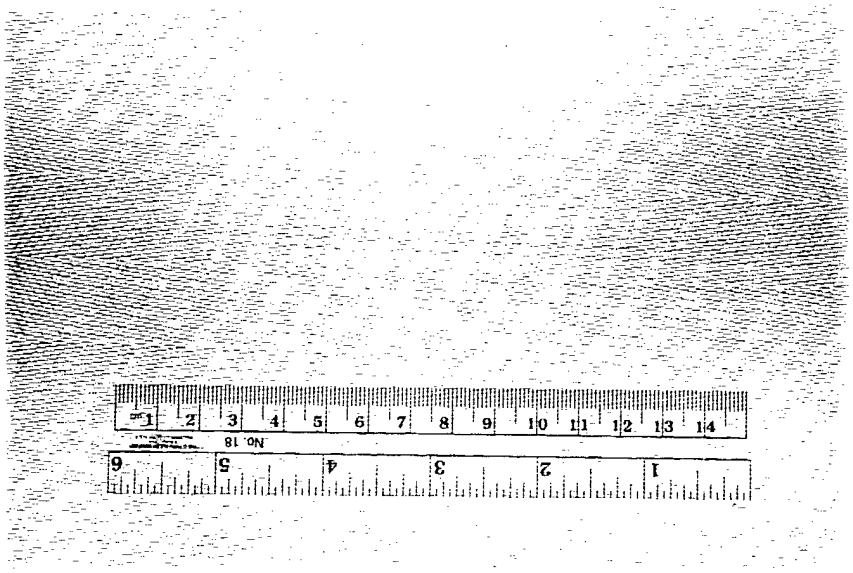


Figure 4.1 (a) Photograph of clean Mauldin Road belt material before press tests.

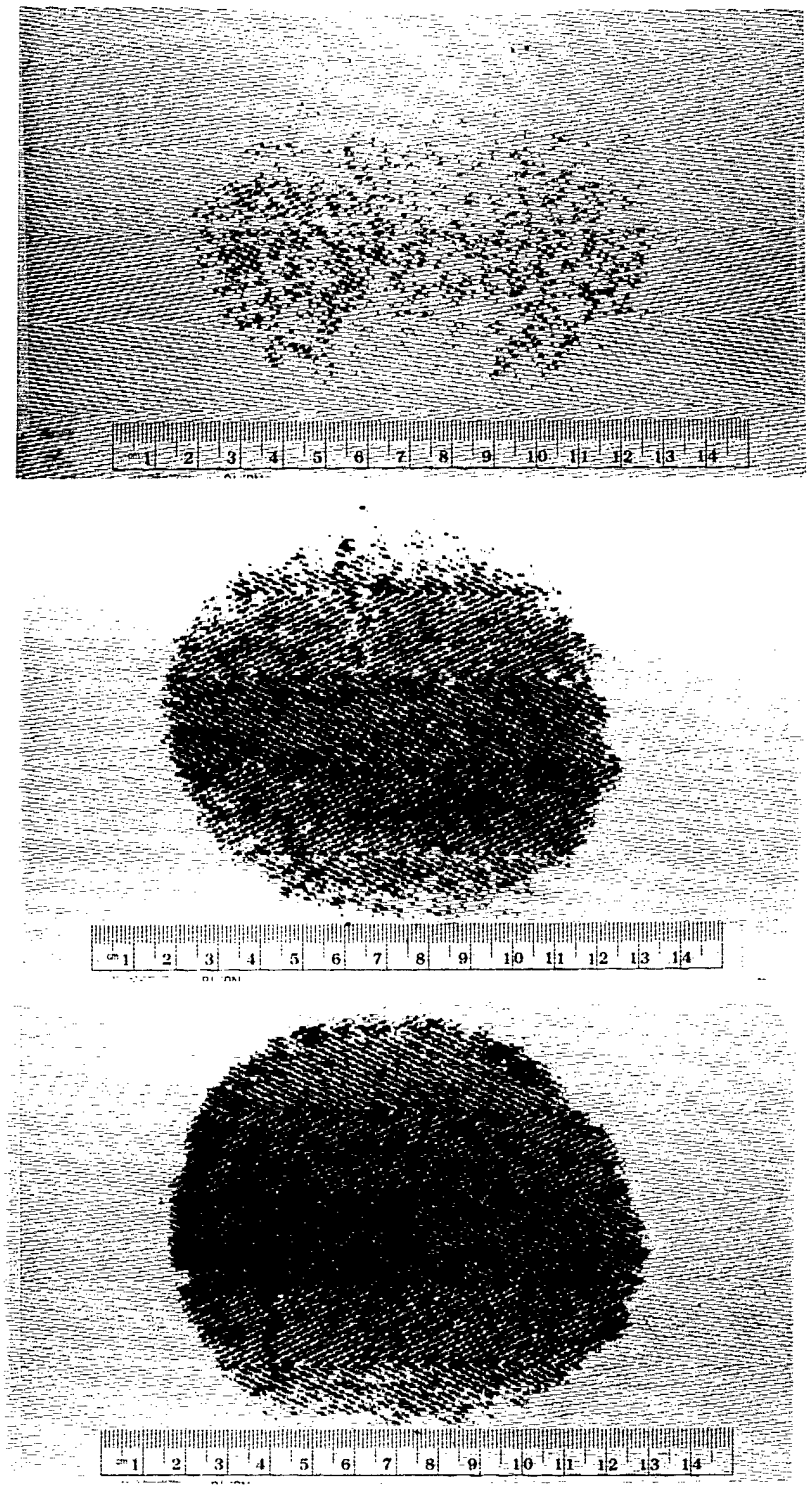


Figure 4.1 Photos of Mauldin Road belt material showing the progression of solids build-up on the belt leading to belt blinding. Sludge pressed at (b) 1.16 psi, (c) 2.41 psi, and (d) 4.90 psi. Sludge conditioned with SD 2085 at 17.7 lb/ton.

4.4 Verification of the Single Press Test with PCS

PCS tests were performed several times during this study. The initial PCS tests served two main purposes. First, they were used to determine how WAS would perform on the Crown Press. Second, they were used to verify the single press test concept developed by Galla et al. (1996) with WAS. These four separate tests demonstrated that the Crown Press was able to replicate BFP dewatering with the plant conditioned WAS. On the days the PCS was collected, the average daily polymer dosage ranged from 7.75 lb/ton to 14.87 lb/ton and the overall average polymer dosage was 10.11 lb/ton. As indicated by the varying polymer dose, the operating parameters for each sampling day were slightly different. The average daily BFP operating data for the four PCS sampling days are listed in Table 4.4.

Table 4.4 BFP operating parameters on PCS sampling days.

	5/6/97	6/5/97	6/24/97	7/11/97
Actual Belt Speed, ft/min	23.5	24.1	N/A*	25.8
Sludge Flowrate, GPM	81	87	93.67	101
Polymer Flowrate, GPM	4.17	3.67	2.73	4.17
Influent Sludge Concentration	2.93%	3.49%	3.58%	3.65%
Polymer Concentration	0.42%	0.41%	0.50%	0.34%
Sludge Loading, lbs/hr	1188	1519	1679	1845
Polymer Dosage, lb/ton	14.87	9.90	8.15	7.75
Final Cake Solids[+], %	14.53	13.73	15.44	14.12

*Value not recorded.
[+]Microwave analyzed.

The sludge loading rate and the polymer dosage were calculated using the following equations:

$$BFP\,Sludge\,Loading\left(\frac{dry\,lb}{hr}\right)=\frac{Q_S\times C_S\times 8.34\frac{lb}{gal}\times 60\frac{min}{hr}}{100}, \qquad (4.2)$$

$$BFP\,Polymer\,Dosage\left(\frac{dry\,lb}{dry\,ton}\right)=\frac{Q_P\times C_P\times 8.34\frac{lb}{gal}\times 60\frac{min}{hr}}{Sludge\,Loading\times 100}\times 2000\frac{lb}{ton}, \qquad (4.3)$$

where Q_S is the sludge flowrate in gpm;
C_S is the influent sludge concentration in % solids;
Q_P is the polymer flowrate in gpm;
C_P is the polymer concentration in % solids.

Figure 4.2 show the results of the first PCS test (5/6/97). The sludge was taken from the front of the gravity drainage section. On the day the sludge was collected, the average polymer dosage was 14.87 lb/ton with ES 1598 and the average cake solids were 14.53%. Four single press tests were performed at 2.41, 3.66, and 4.90 psi for 10, 20, 40, and 60 seconds. Figure 4.2a shows the relationship between final cake solids, pressure and time under pressure. The trends shown in these figures mimic the results that were reported by Galla et al. (1996) for PCS. As the pressure exerted on the sludge and the time under pressure increased the final cake solids increased. Figure 4.2b shows the condensed data, which followed the same linear trend observed by Galla et al. (1996). The linear regression line of the data fell within the typical BFP operating region, which is described below.

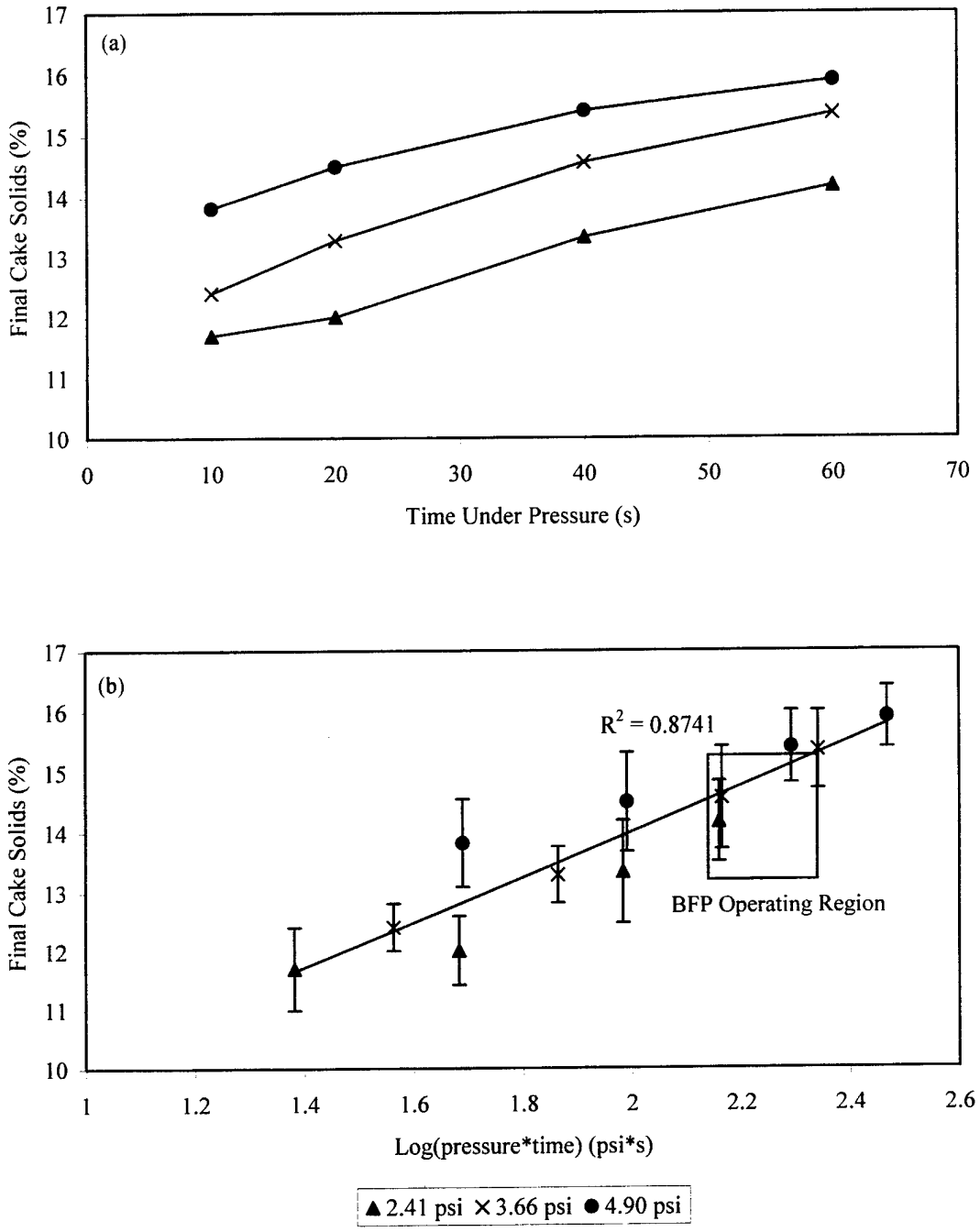


Figure 4.2 Crown Press dewatering of PCS dosed at 14.87 lb/ton with ES 1598; (a) the effect of three different pressures on final cake solids; and (b) condensed data with linear regression. Error bars represent ± 1 standard deviation of sample average.

The box in Figure 4.2b represents the typical BFP operating region for the Mauldin Road BFPs. The vertical limits of the box represent a nine-month average (December 1996 through August 1997) of microwave analyzed final percent cake solids (14.2%), plus and minus one standard deviation (1.0%). The horizontal limits of the box were determined using the upper and lower values for actual belt speeds and belt tensions to calculate time under pressure and pressure for each roller. The belt tensions were determined by converting hydraulic pressures using an algorithm provided by technical personnel at Eimco which can translate known hydraulic cylinder pressures to belt lineal tensions, which is provided in the Appendix. The belt tensions were then used to determine the pressure on each roller using Equation 4.4. Time under pressure was determined using the wrap angle of the belts on the BFP, the diameters of the rollers, and the belt speed of the BFP. The following equation shows this calculation:

$$t = \frac{r\theta}{V}, \tag{4.4}$$

where

t = time under pressure (s)
r = radius of roller (in)
θ = wrap angle (rad)
V = belt speed (in/s).

The product of the pressure and time under pressure for each roller were summed and the log of the sum calculated. The lower horizontal limit of the operating region was calculated using the highest belt speed and the lowest belt tension used on the BFP. The higher horizontal limit was calculated using the lowest belt speed and the highest belt tension. Table 4.5 shows the data used to calculate the horizontal BFP operating range limits for the Mauldin Road Eimco presses.

As can be seen in Figure 4.2b the horizontal operating region for the full scale presses is to the far right of the plot at high log (pressure*time) values. This is due to the high belt tensions currently being used on all presses. Because the presses are operating at the upper limit for hydraulic pressure, pressures (belt lineal tensions) in excess of those currently being used on the BFP were not examined on the Crown Press.

Table 4.5 Horizontal operating range calculations for Eimco secondary belt filter presses.

				Lower Extreme			Upper Extreme		
				Belt Tension (lb/in) =		36.48	Belt Tension (lb/in) =		47.05
				Belt Speed (in/s) =		5.6	Belt Speed (in/s) =		4.5
Roller #	Roller Diameter (in)	Wrap Angle (degrees)	Wrap Angle (rad)	Time Under Pressure (s)	Pressure (psi)	Pressure * Time (psi-s)	Time Under Pressure (s)	Pressure (psi)	Pressure * Time (psi-s)
1	36	209.439	3.655	12	2.03	23.81	15	2.61	38.22
2	18	118.023	2.060	3.3	4.05	13.42	4.1	5.23	21.54
3	11	161.094	2.812	2.8	6.63	18.31	3.4	8.56	29.40
4	11	167.288	2.920	2.9	6.63	19.02	3.6	8.56	30.53
5	11	169.204	2.953	2.9	6.63	19.24	3.6	8.56	30.88
6	9	169.531	2.959	2.4	8.11	19.27	3.0	10.46	30.94
7	9	140.957	2.460	2.0	8.11	16.03	2.5	10.46	25.72
8	11	64.99	1.134	1.1	6.63	7.39	1.4	8.56	11.86
Sum				29.1		136.48	36.2		219.09
log (pressure * time)						2.14			2.34

The results of the three other PCS tests are provided below. The condensed data from 6/5/97 and 7/11/97 are shown in Figures 4.3 and 4.4, respectively. In both PCS tests, the linear regression line fell within the plant's BFP operating region. Pressures higher than 3.66 psi were not tested because sludge began to squeeze through the belts and clog the belt weave leading to severe belt blinding.

In addition to testing PCS from 6/24/97, influent sludge and polymer solution were also collected in order to test LCS on the Crown Press. The influent sludge was conditioned with the plant's polymer solution according to procedures outlined in Chapter 3 at a dosage of 14 lb/ton. Figure 4.5 shows the results from these PCS and LCS tests. The LCS was not pressed above 2.41 psi due to blinding, which is lower than the upper pressure of 3.66 psi tested on the PCS. The data for both tests follow the same linear trends observed in the other three PCS tests.

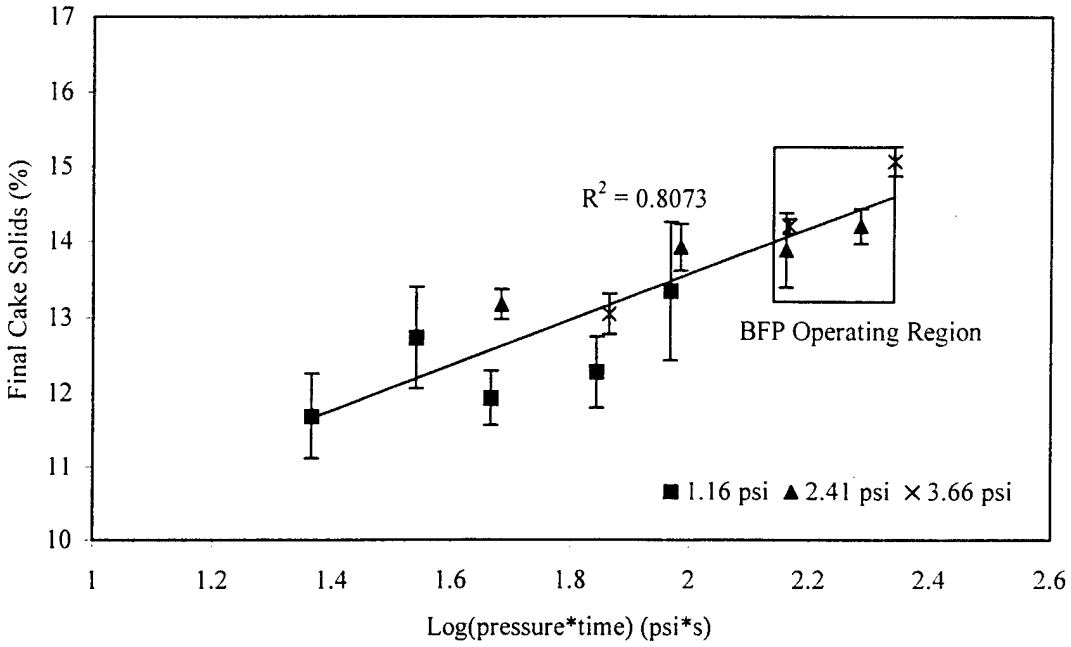


Figure 4.3 Crown Press dewatering of PCS dosed at 9.90 lb/ton with ES 1598. Error bars represent ± 1 standard deviation of sample average.

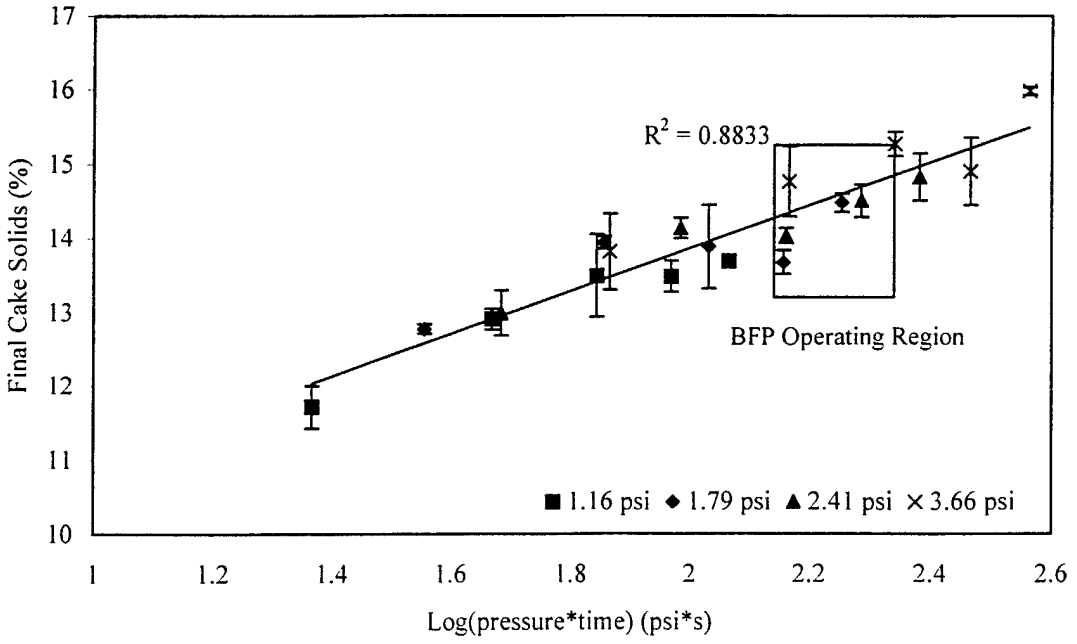


Figure 4.4 Crown Press dewatering of PCS dosed at 7.75 lb/ton with ES 1598. Error bars represent ± 1 standard deviation of sample average.

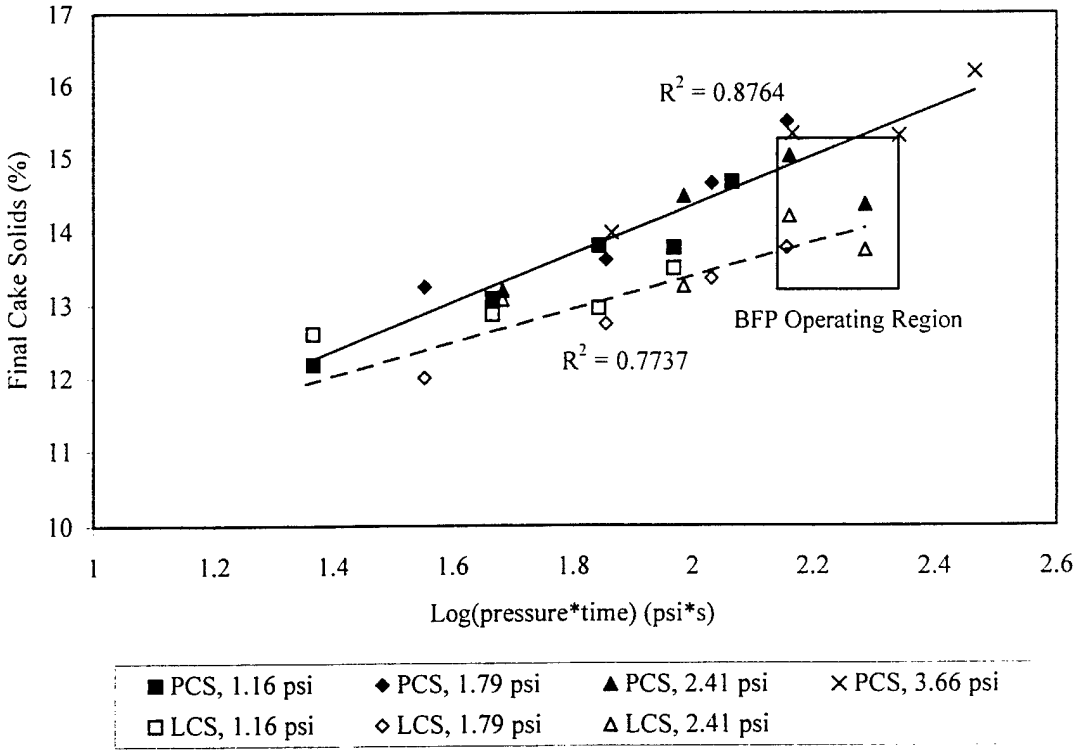


Figure 4.5 Crown Press dewatering of PCS dosed at 8.15 lb/ton and LCS dosed at 14 lb/ton with ES 1598. Dashed regression line is for LCS data and solid line is for PCS.

As can be seen in Figure 4.5, LCS final cake solids were as much as 1.7% solids lower than the PCS cake solids. These results agree with those reported by Galla et al. (1996) for a side-by-side comparison of Crown Press dewatering of LCS and PCS. Their studies found that at similar polymer doses LCS final cake solids were lower than the PCS final cake solids. It is indicated above that the LCS was dosed approximately 6 lb/ton higher than the PCS. The higher dose was necessary to produce a cake that was pressable on the Crown Press. Attempting to dewater LCS dosed at 8 lb/ton resulted in a conditioned sludge which ran off the top of the crown when squeezed between the belts. Thus the polymer dose was increased until a pressable conditioned sludge was achieved.

These PCS and LCS tests verified that the single press test developed by Galla et al. (1996) is a viable tool to use with the WAS from the Mauldin Road facility. This is evident by the linearity of the regression lines for PCS data which passed through Mauldin Road's BFP operating region. It was also found that when the LCS was dosed at less than 10 lb/ton, pressures higher than 3.66 psi could not be tested due to significant belt blinding.

4.5 Evaluation of Polymers

One of the goals of this project was to identify a polymer that would produce dewatered cakes solids on the Crown Press that were higher than the cake solids achieved with the plant's current polymer. Alternatively, a polymer was sought that could give equivalent performance but at significant cost savings over the current polymer. The five polymers tested are listed in Table 3.2. Two of the products tested were emulsion polymers, two were liquid dispersion polymers, and one was a dry polymer. These polymers in no way exhausted the potential supply of polymer types or manufacturers. Each of the polymers was tested on the Crown Press using a range of doses, pressures, and times under pressure. In addition to the press tests, CST and SRF were used to assess the potential dewaterability of the conditioned sludge. Solids capture efficiency was also determined for two of the polymer press tests. The information collected from these tests was used to select the polymers which would be tested on a full-scale level using the BFPs at the Mauldin Road facility.

4.5.1 Environmental Specialties (ES) 1598

ES 1598 is a high cationic charge, high molecular weight dry polymer produced by Allied Colloids and distributed by numerous vendors, including Environmental Specialties. The Mauldin Road facility has been using this polymer to condition WAS for approximately three years. The polymer is delivered in a dry form that is 95% active product. The plant mixes the polymer with water to form a solution with a concentration of 0.30% to 0.50%. In the lab, a polymer solution of 0.40% was prepared to condition influent sludge for CST and SRF tests. Conditioned sludge samples with polymer doses between 4.5 and 15.1 lb/ton were tested. The results of these CST and SRF tests are shown in Figure 4.6. The minimum CST and SRF values were between 7 and 12 lb/ton, which incorporates the plant's typical operating range for polymer dose.

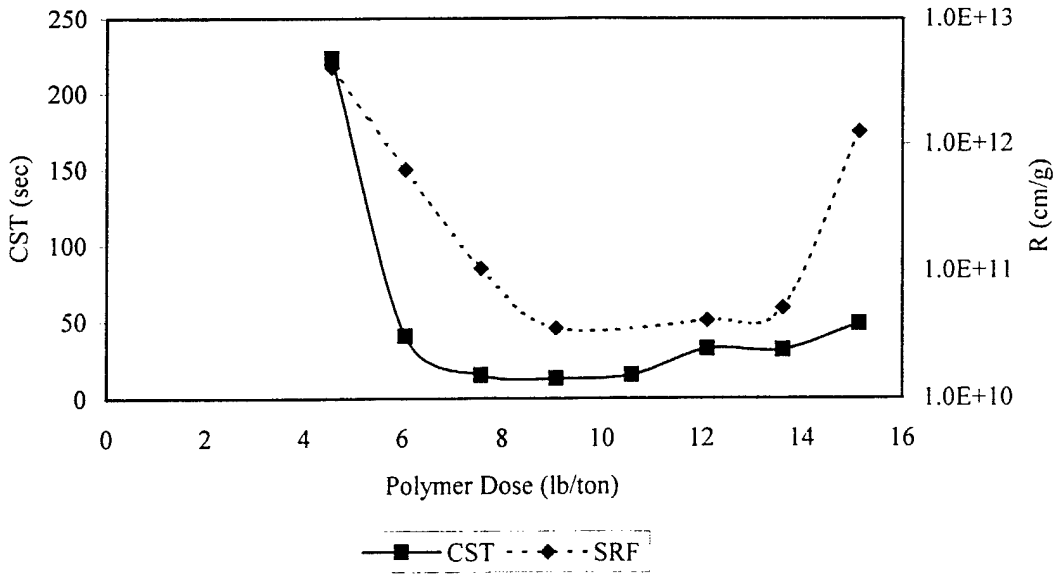


Figure 4.6 CST and SRF tests for sludge conditioned with ES 1598.

4.5.2 Cytec's Superfloc® SD 2081

Superfloc SD 2081, referred to as SD 2081, is a high cationic charge, high molecular weight emulsion polymer. Cytec supplies this product at an activity of 41%, which means that in 100 pounds of supplied product, 41 pounds are active polymer. Polymer dilutions between 3.80 g/L and 4.0 g/L, or 0.38% - 0.40%, were used during lab testing. Figure 4.7 shows the results of the CST and SRF tests for polymer doses between 7.4 and 16.3 lb/ton. Both CST and SRF indicated that polymer doses between 11 and 13.5 lb/ton should provide good dewaterability, which is the approximate range of the minimum values for these plots.

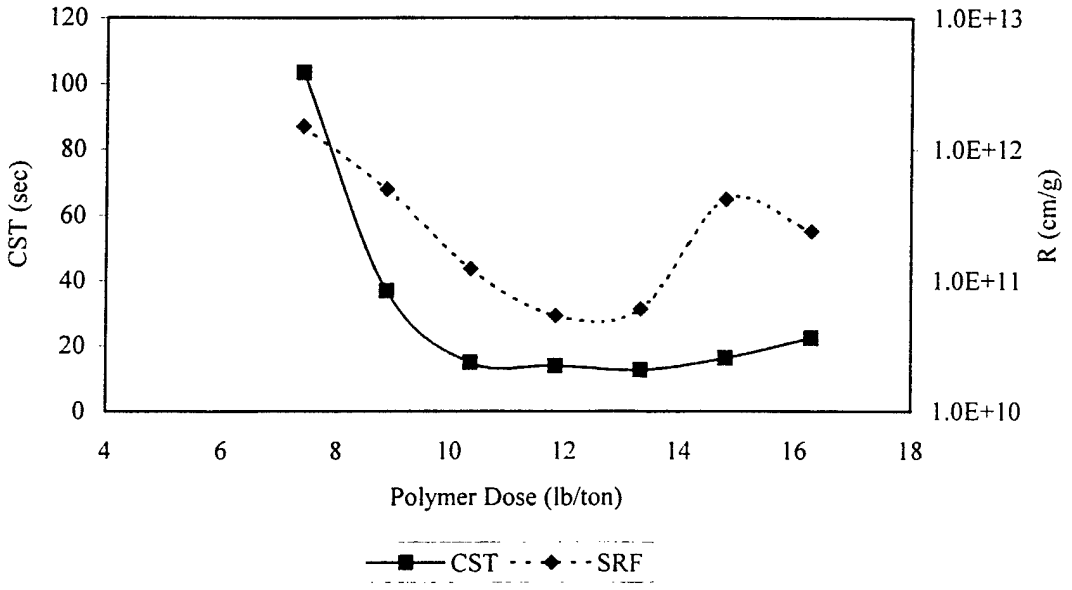


Figure 4.7 CST and SRF tests for sludge conditioned with SD 2081.

The results from the CST and SRF tests were used to select the initial polymer dose of 12.3 lb/ton for testing on the Crown Press. Then the minimum dose that produced a pressable cake was tested, which was 9.3 lb/ton. Two doses above the initial dose were also tested, 15.4 and 22.7 lb/ton. From Figure 4.7, these polymer doses are higher than the doses that resulted in the minimum CST and SRF values. These higher doses were evaluated to determine how a polymer dose that resulted in deteriorated CST and SRF values would perform on the Crown Press. With the exception of 9.3 lb/ton, all doses were tested at 1.16, 2.41, and 3.66 psi for 15, 30, 45, and 60 seconds. Sludge conditioned at 9.3 lb/ton could not withstand pressures above 2.41 psi without severely blinding the belts. This was an indication that the sludge was being underdosed at 9.3 lb/ton and needed a higher polymer dose to withstand the higher pressures.

Figure 4.8 shows the Crown Press results for these press tests. The data for each polymer dose fit a linear regression, as indicated by the R^2 values of 0.86, 0.78, 0.90, and 0.94 for 9.3, 12.3, 15.4, and 22.7 lb/ton, respectively. These results show that as the polymer dose increases, the cake solids concentration at a given log(pressure*time) value increases, but with diminishing returns. This is evident by the distance between the linear fits decreasing with increasing polymer dose. It is important to note that final cake solids over 15% were achieved using SD 2081 at three of the four polymer doses. These concentrations were higher than Mauldin Road's average cake solids, and therefore suggested that this polymer would make a good candidate for BFP testing.

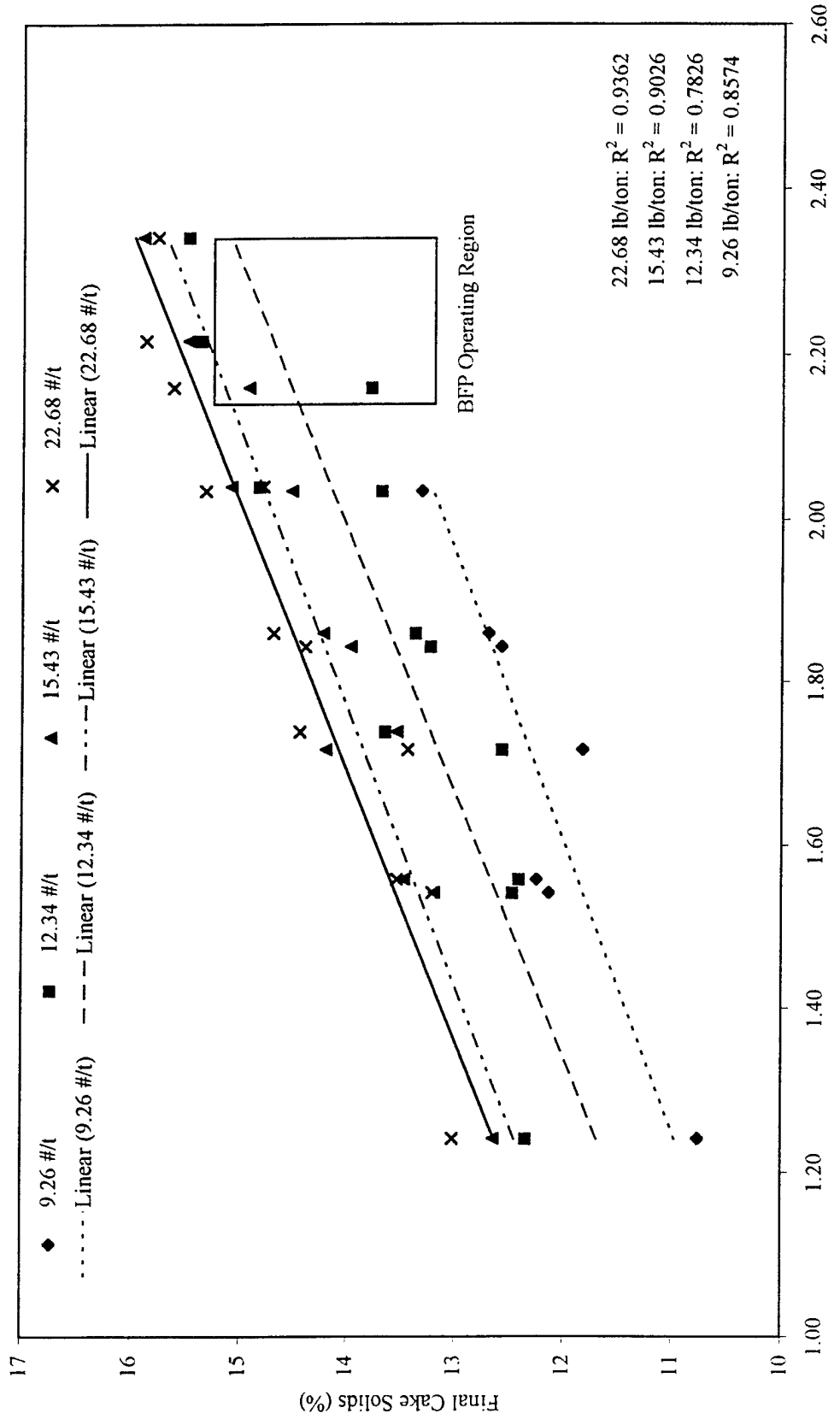


Figure 4.8 Crown Press polymer evaluation test for sludge conditioned with Superfloc SD 2081 using a 0.39% polymer

4.5.3 Cytec's Superfloc® SD 2085

Superfloc SD 2085 is also a high molecular weight emulsion polymer but has a higher cationic charge than SD 2081. This polymer also is 41% active product. Polymer dilutions between 0.39% and 0.41% were prepared for lab polymer testing. CST and SRF were determined for polymer dosages between 7.3 and 20.5 lb/ton. These results are provided in Figure 4.9. The minimum CST and SRF values were between 13 and 17 lb/ton, suggesting that good dewaterability could be achieved in this range of polymer doses.

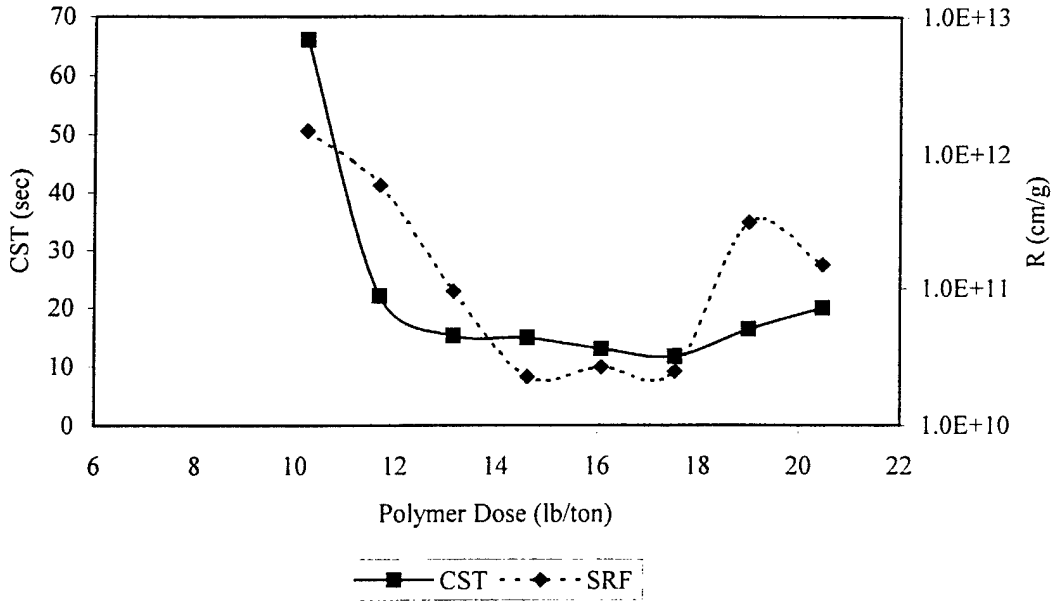


Figure 4.9 CST and SRF tests for sludge conditioned with SD 2085.

Sludge was then conditioned with SD 2085 and evaluated on the Crown Press at four polymer dosages. The polymer was mixed with water to provide a dilution concentration of 0.40%. Using the results from the CST and SRF tests, the first polymer dose tested on the Crown Press was 13.2 lb/ton. The highest pressure that could be tested at this polymer dose was 3.66 psi. Under this pressure, higher quantities of solids remained in the belt weave after removing the dewatered cake from the belt. The belts also became more difficult to clean. Both of these indicated that the belts were beginning to blind. At 4.90 psi, sludge squeezed through the belt fabric and a larger portion of the solids remained in the weave after removing the cake. Thus, 4.90 psi was not tested. The other pressures tested at 13.2 lb/ton were 1.16 and 2.41 psi. Each pressure was tested at 15, 30, 45, and 60 seconds. The polymer dose was then increased to 15.2 lb/ton, 18.2 lb/ton and 21.6 lb/ton. For each polymer dose, four pressures were tested: 1.16, 2.41, 3.66, and 4.90 psi. Press tests at pressures above 4.90 psi resulted in severe blinding, therefore 4.90 psi was used as the cut-off point.

The results from this Crown Press polymer evaluation are shown in Figures 4.10-4.14. In general, these polymer evaluations with the single press test followed the same trend as the PCS single press tests. With the exception of a few data points among the four polymer doses tested, an increase of pressure and time under pressure resulted in an increase of final cake solid concentration. As can be seen in the linearized data in Figure 4.14, SD 2085 achieved dewatered cake solids with concentrations higher than the upper limit of the plant's normal operating region (15.2%). Over 30% of the press tests resulted in cake solids higher than 15.2% solids and were obtained under a variety of operating

conditions. In addition, over 80% of the data points fell above the minimum final cake solids concentration of the plant's operating region (13.2%).

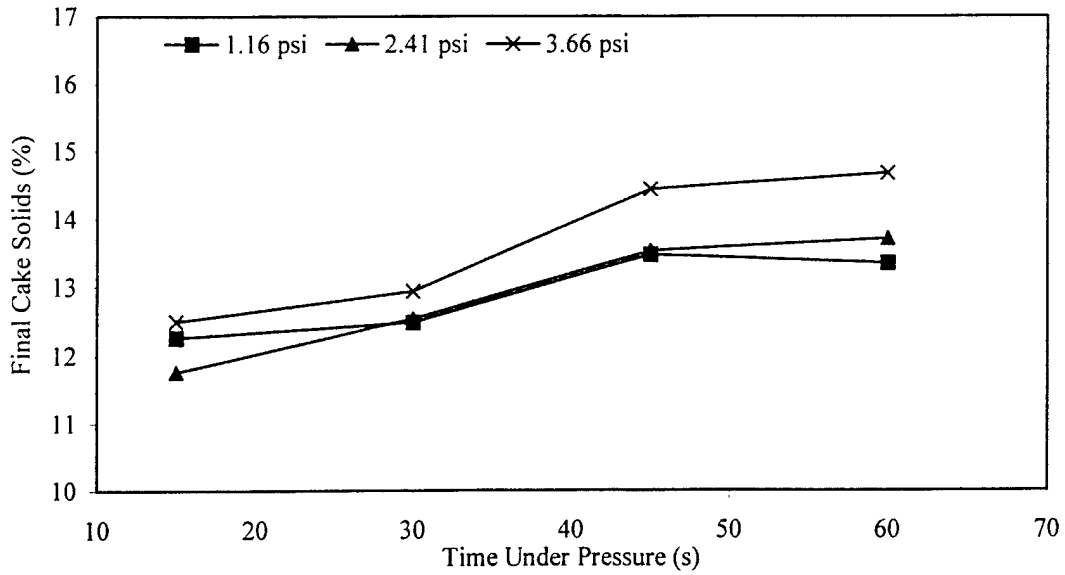


Figure 4.10 Crown Press polymer evaluation test with SD 2085 at 13.2 lb/ton.

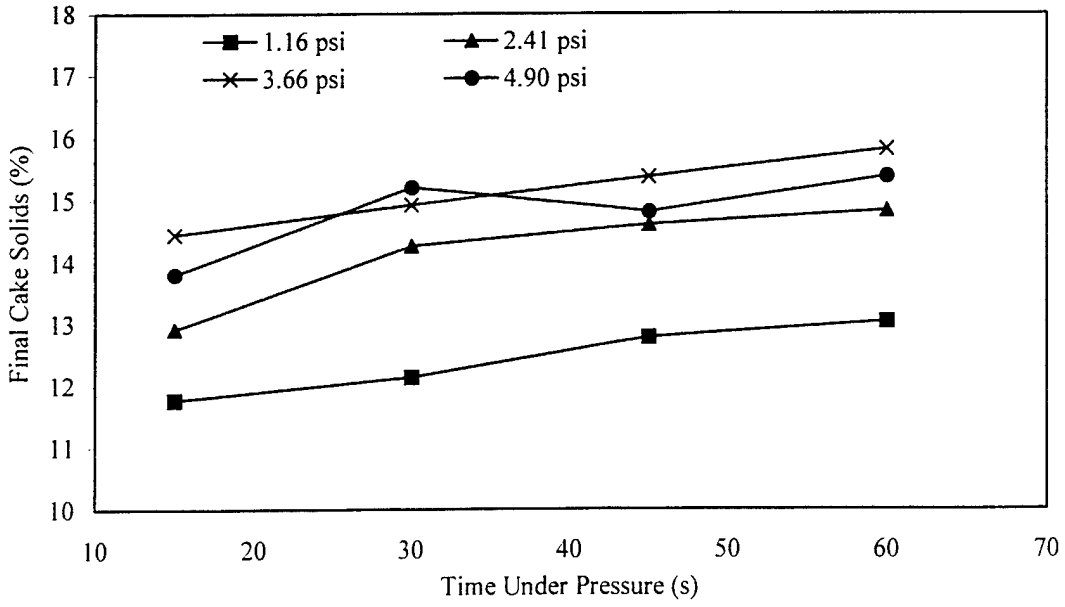


Figure 4.11 Crown Press polymer evaluation test with SD 2085 at 15.2 lb/ton.

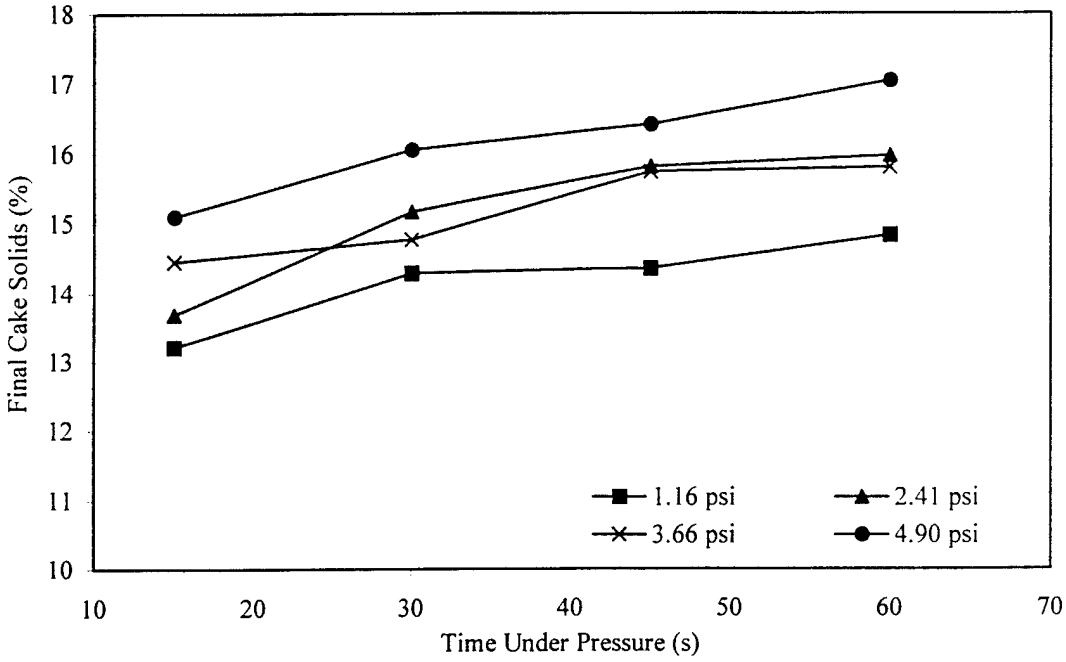


Figure 4.12 Crown Press polymer evaluation test with SD 2085 at 18.2 lb/ton.

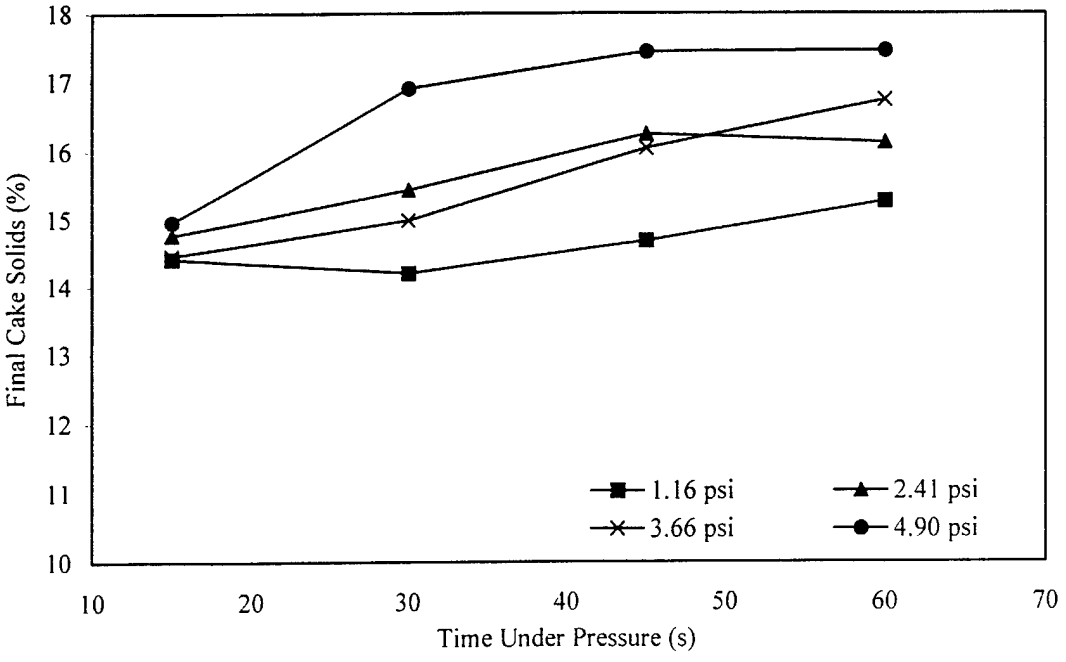


Figure 4.13 Crown Press polymer evaluation test with SD 2085 at 21.6 lb/ton.

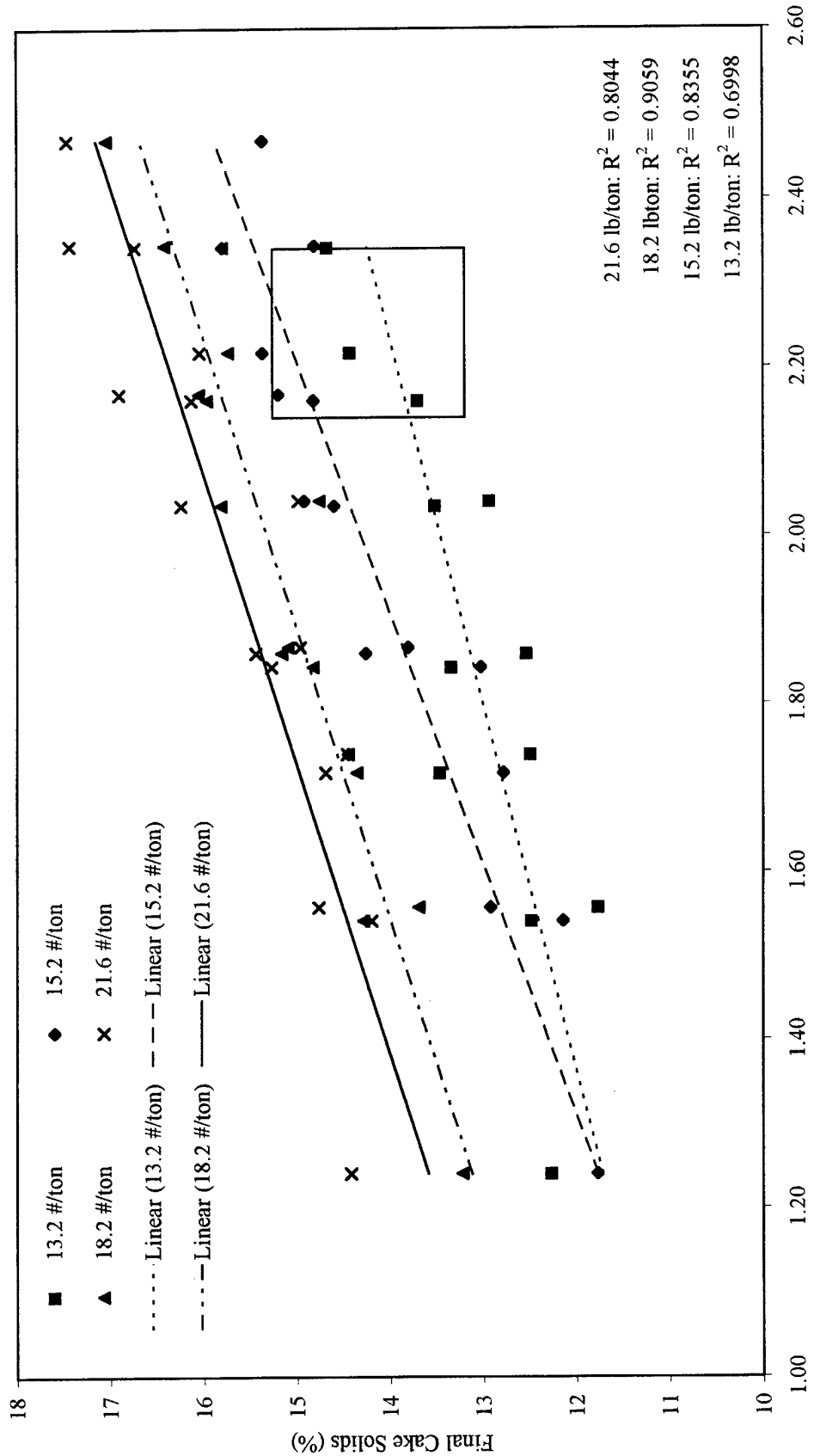


Figure 4.14 Crown Press evaluation test for sludge conditioned with Superfloc SD 2085, linearized data from Figures 4.10-4.13.

The diminishing returns seen in the data from the SD 2081 tests were also found in the results from the SD 2085 single press tests. This indicates that there is an upper limit to the polymer dosage that can be applied to a sludge, beyond which there is no improvement in cake solids. Above this upper polymer dose, the cake solids concentrations will either stay the same or begin to decrease due to overdosing. Most facilities do not operate at such a high polymer dose. Typically the small percentage increase in dewatered cake solids is not worth the large percentage increase in polymer demand.

In addition to evaluating the performance of SD 2085 based on cake solid concentrations, solids recovery was also determined for each press test. Pressate and belt wash water were collected for each press test and evaluated for suspended solids. The solids concentrations were used to calculate a mass balance and to determine the solids capture efficiency for the press test as described in Chapter 3. Figure 4.15 shows the results of the capture efficiency calculations for SD 2085 evaluation on the Crown Press. The four capture efficiencies for each pressure tested (one at each time under pressure) were averaged. These were plotted versus the pressure of the press test for each polymer dose. As the pressure increased, the average capture efficiency decreased for each polymer dose tested. There is a distinct separation between the curves for the lower two and the upper two polymer doses. This suggests that the lower polymer doses were not as effective in conditioning the sludge as the upper polymer doses. These results confirmed visual observations concerning the condition of the belts after a press test. After press tests at the higher two polymer doses, the belts contained less solids and were

easier to clean with a smaller volume of water. The belts after press tests at 13.2 and 15.2 lb/ton, in general, contained more solids and required a larger volume of water to clean.

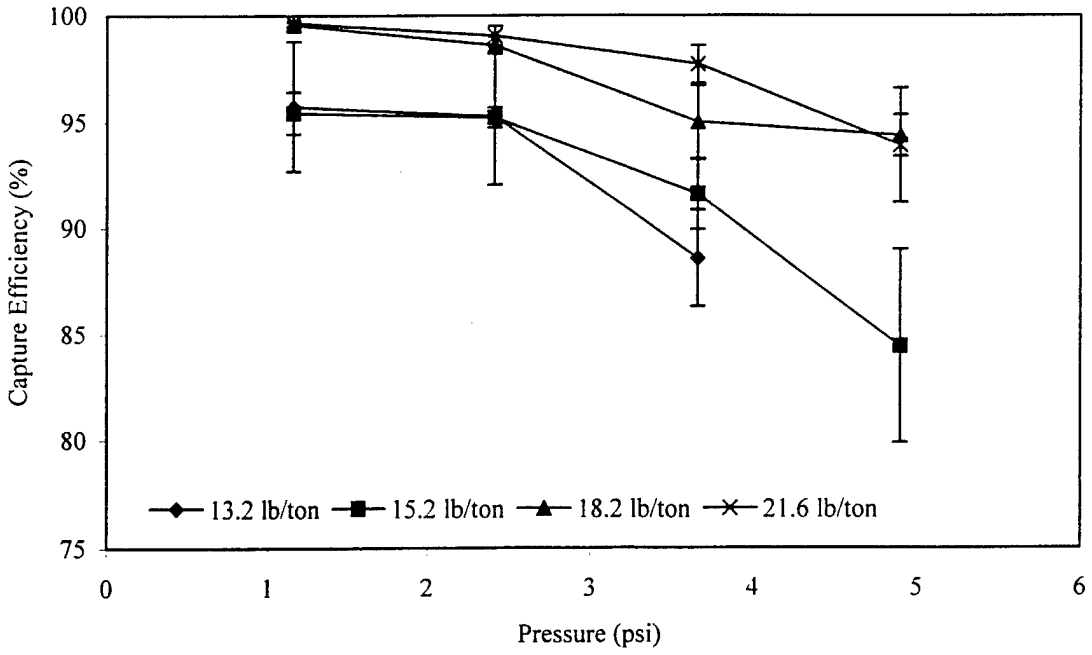


Figure 4.15 Capture efficiencies for the Crown Press tests evaluating SD 2085. Each data point is the average of four capture efficiencies for each time under pressure tested at the given pressure. Error bars represent ±1 standard deviation of sample average.

Overall, the results from the Crown Press evaluation of SD 2085 indicated that this polymer was able to effectively condition the sludge to achieve final cake solid concentrations that were as much as 2.2% solids higher than the upper limit of Mauldin Road's BFP operating region. Every polymer dose produced final cakes either within or above vertical limits of the operating region over a wide range of pressure and time under pressure values. The polymer doses that resulted in the high cake solids were considerably higher than the doses typically used at the plant. However, if these results

are achievable on the BFPs, the plant could realize an improvement in cake solids that offsets the cost of a higher dose. For these reasons, SD 2085 was one of the polymers selected for testing on the BFPs at the Mauldin Road facility.

The prediction that SD 2085 can achieve cake solids higher than ES 1598 could not have been made based on the CST and SRF tests. The only prediction that could be made with the CST and SRF results was that the SD 2085 dose required for effective dewatering was higher than the ES 1598 dose. This does not indicate anything about the potential cake solids with SD 2085.

4.5.4 Cytec's Superfloc® C-496

The third Cytec polymer evaluated with the Crown Press was Superfloc C-496. This dry polymer has a high cationic charge and high molecular weight and is supplied with an approximate activity of 90%. A stock polymer dilution was prepared with a concentration of 0.50% to be used in CST, SRF and press tests. Figure 4.16 shows the results from the CST and SRF tests over a range of polymer doses. These tests indicated that doses between 10 and 14 lb/ton should provide effective dewatering.

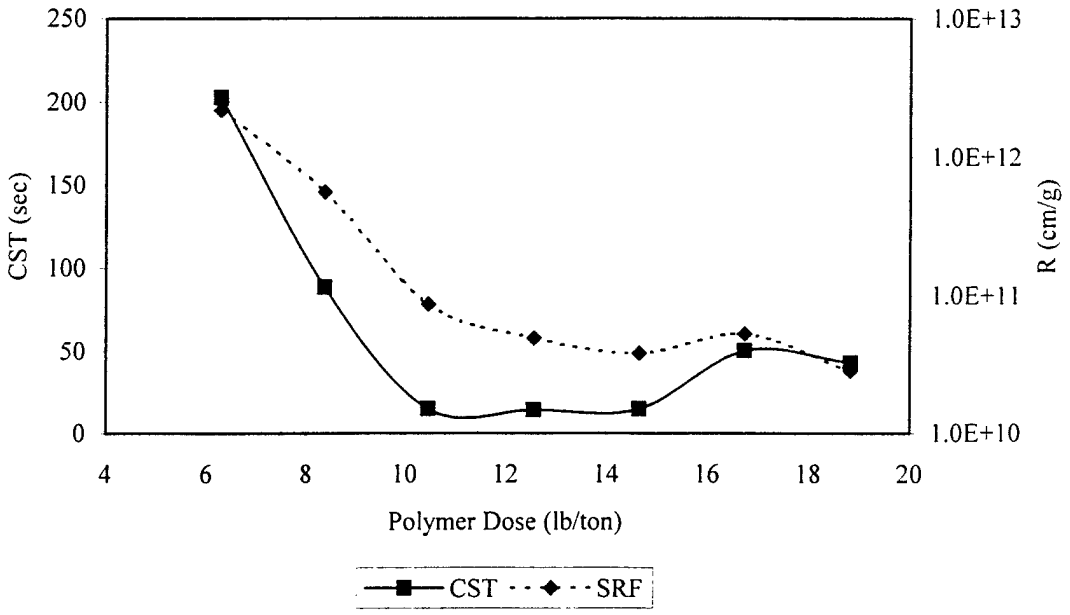


Figure 4.16 CST and SRF tests for sludge conditioned with Superfloc C-496.

Using the CST and SRF test results, three polymer doses were chosen to be evaluated on the Crown Press: 10.9, 15.3 and 19.6 lb/ton. The highest pressure that did not result in significant blinding for all of the doses was 3.66 psi. Thus, the three pressures tested were 1.16, 2.41, and 3.66 psi. Figure 4.17 shows the linearized data for the three polymer doses evaluated.

The final cake solid concentrations achieved with Superfloc C-496 were below the lower limit (13.2%) of Mauldin Road's operating region. There was little variation in the results from the three polymer doses evaluated, as shown by the closeness of the linear regressions for each set of data. In general, the low final cake solids and the blinding at lower pressures suggested that Superfloc C-496 is not well suited for this particular sludge. This polymer was not considered for full-scale evaluation.

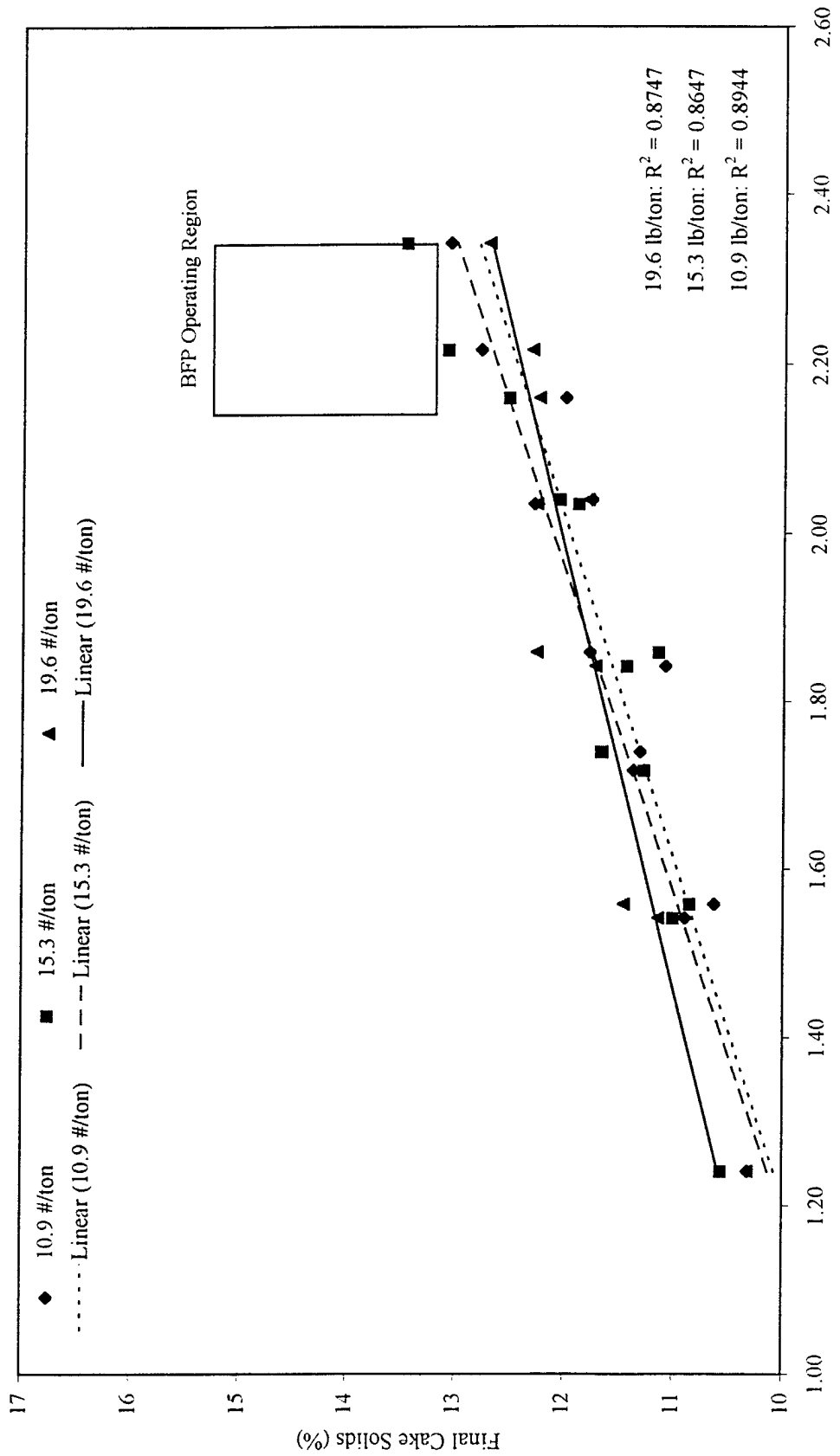


Figure 4.17 Crown Press polymer evaluation test for sludge conditioned with Superfloc C-496 using a 0.50% polymer solution.

4.5.5 Percol 775 FS25

The Percol 775 FS series of polymers are high molecular weight, cationic polyelectrolytes produced by Allied Colloids. These polymers are supplied as liquid dispersions in light mineral oil and dissolve readily in water to produce solutions of high viscosity. A 1.0% active solution of a 775 FS polymer has a viscosity of roughly 8500 cP. They also exhibit a very high cationic charge, on the order of 60%. Percol 775 FS polymers were designed specifically as a flocculent for WAS and aerobically digested municipal sludges.

Percol 775 FS25 is a liquid dispersion polymer with 50% active product. Polymer solutions of 0.50% were prepared for lab testing. Conditioned sludge samples with polymer doses between 8.9 and 22.3 lb/ton were prepared for CST and SRF tests. The results of these tests are shown in Figure 4.18. Based on the minimum CST and SRF values, four polymer doses were evaluated on the Crown Press: 12.6, 14.7, 17.1, and 19.2 lb/ton. With a polymer dose of 12.6 lb/ton, the highest pressure that could be used without causing severe blinding of the belts was 3.66 psi. At 3.66 psi, the belts were beginning to exhibit blinding characteristics, therefore higher pressures were not tested. With the three higher polymer doses, 4.90 psi was the highest pressure tested. For each polymer dose, the final cake solids data followed the same linear trend as the previous polymer evaluations and PCS tests. The final cake solids data for the four polymer doses evaluated are shown in the linear form in Figure 4.19.

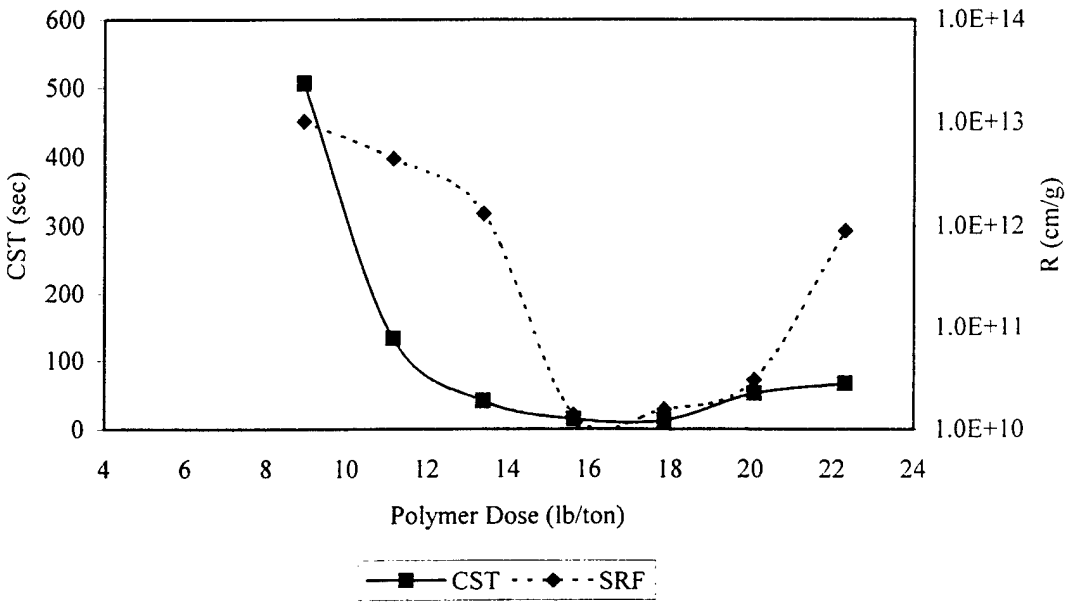


Figure 4.18 CST and SRF tests for sludge conditioned with Percol 775 FS25

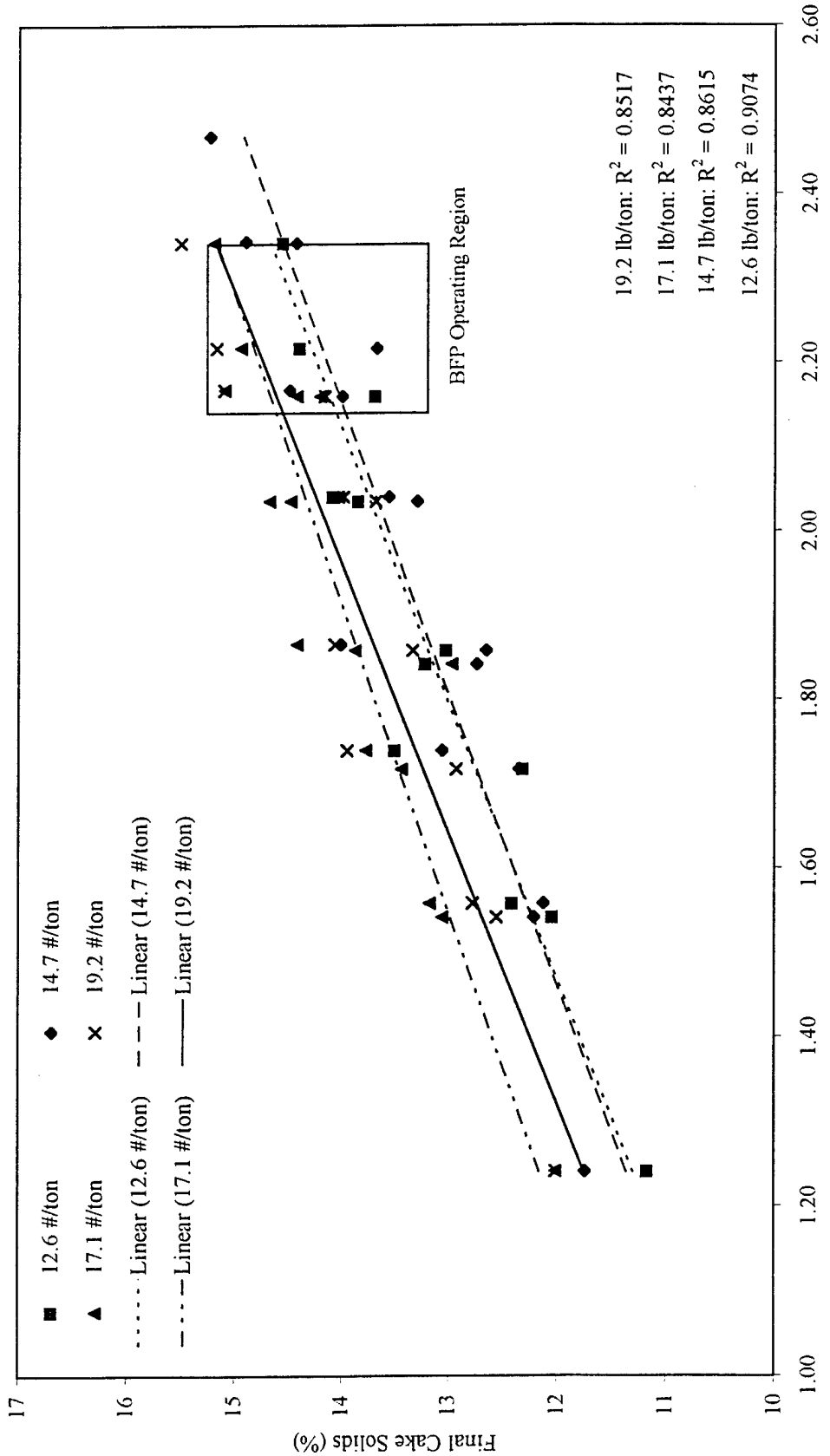


Figure 4.19 Crown Press polymer evaluation test for sludge conditioned with Percol 775 FS25 using a 0.50% polymer solution.

As can be seen in Figure 4.19, the effect of polymer dose on final cake solids was not as dramatic as was seen with Superfloc SD 2085. The lower two polymer doses (12.6 and 14.7 lb/ton) achieved similar cake solid concentrations which is evident from the almost overlapping linear regression lines. Only one press test with the highest polymer dose evaluated achieved a cake solids concentration higher than the upper limit of the BFP operating region. Over one-half of the data points fell within the vertical limits of the BFP operating region. The overall performance Percol 775 FS25 suggested that this polymer would produce final cakes that are similar in concentration to final cakes produced with ES 1598 on the BFP.

In addition to evaluating cake solids, pressate and belt wash water were collected to evaluate the solids recovery for each press test. The results of these capture efficiency calculations are shown in Figure 4.20. Each data point represents the average capture efficiency for each pressure evaluated. The results show that as the pressure increased, the capture efficiency decreased. Unlike the results for Superfloc SD 2085, there was no distinct separation between the polymer doses. The overall trends in capture efficiency data followed the visual observations made concerning the condition of the belts after the press tests.

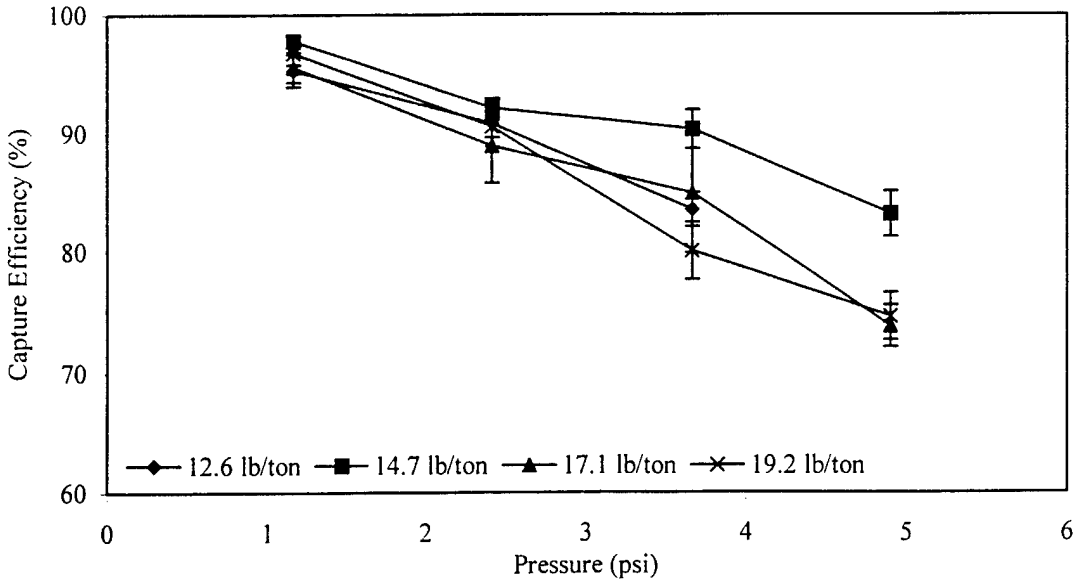


Figure 4.20 Capture efficiencies for the Crown Press tests evaluating Percol 775 FS25. Each data point is the average of four capture efficiencies for each time under pressure tested at the given pressure. Error bars represent ± 1 standard deviation of sample average.

4.5.6 Percol 778 FS25

The Percol 778 FS series of polymer are very similar to the 775 FS series. These are also high molecular weight, cationic polyelectolytes that are supplied as a liquid dispersion in light mineral oil. A 1.0% solution of a 778 FS polymer will have a viscosity of 5000 cP. The difference between the 778 FS and 775 FS series is the cationic charge density. The 778 FS polymers have a high cationic charge density of 80%. The 778 FS series was also designed for WAS and aerobically digested sludge conditioning.

Percol 778 FS25 is a liquid dispersion polymer with 50% active product. Polymer solutions of 0.50% were prepared for lab testing. Conditioned sludge samples with polymer doses between 6.8 and 22.6 lb/ton were prepared for CST and SRF tests. The

results of these tests are shown in Figure 4.21, which suggest that good dewaterability would occur with polymer doses starting between 10 and 11 lb/ton and higher. Four polymer doses were evaluated on the Crown Press: 10.0, 12.0, 16.0, and 19.0 lb/ton. Each dose was tested at 1.16, 2.41, 3.66, and 4.90 psi for four different time intervals, with the exception of 10.0 and 19.0 lb/ton. These two polymer doses experienced severe blinding at 4.90 psi, therefore this pressure was not included in testing.

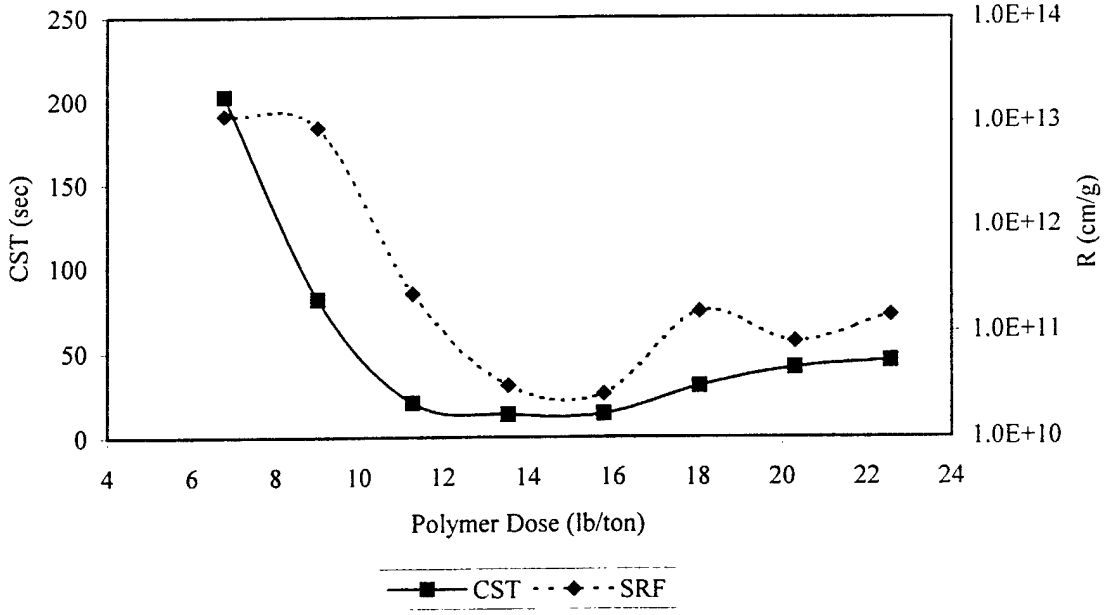


Figure 4.21 CST and SRF tests for sludge conditioned with Percol 778 FS25.

Figure 4.22 shows the results from the four polymer doses evaluated. The linear regression fits for the four polymer doses all fell above the BFP operating region. Each polymer dose achieved final cake solids higher than the upper limit of the operating region (15.2%), and over 90% of the press tests resulted in final cake solid concentrations higher than the lower limit of the operating region. Unlike the linearized data from the SD 2085 tests, the data from Percol 778 FS25 were clumped together. This is evident in the data from the lowest and highest polymer doses. The increase from 10 lb/ton to 19 lb/ton represents a 90% increase in polymer dose. However, the cake solids only increased an average of 0.69% solids. Table 4.6 summarizes the change in final cake solids between the lowest polymer dose tested (10 lb/ton) and each subsequent higher dose. This data demonstrates that there is a trade-off between increased polymer dose and the higher cake solids. This will obviously be driven by the cost of the polymer.

Table 4.6 Summary of change in operating parameters compared to 10.0 lb/ton of Percol 778 FS25. Solids concentrations are based on the average concentration for all press tests at a given polymer dosage.

	Percol 778 FS25 Dose		
	12.0 lb/ton	**16.0 lb/ton**	**19.0 lb/ton**
Percent increase in polymer dose	20%	60%	90%
Average increase in solids concentration	0.40% ± 0.90%	0.26% ± 0.72%	0.69% ± 0.54%

The overall performance of Percol 778 FS25 was very positive. This polymer was able to achieve cake solids as much as 1.3% solids higher than the upper limit of Mauldin Road's operating region. Because of the predicted improvement in cake solids, this polymer was another potential choice for full-scale evaluation.

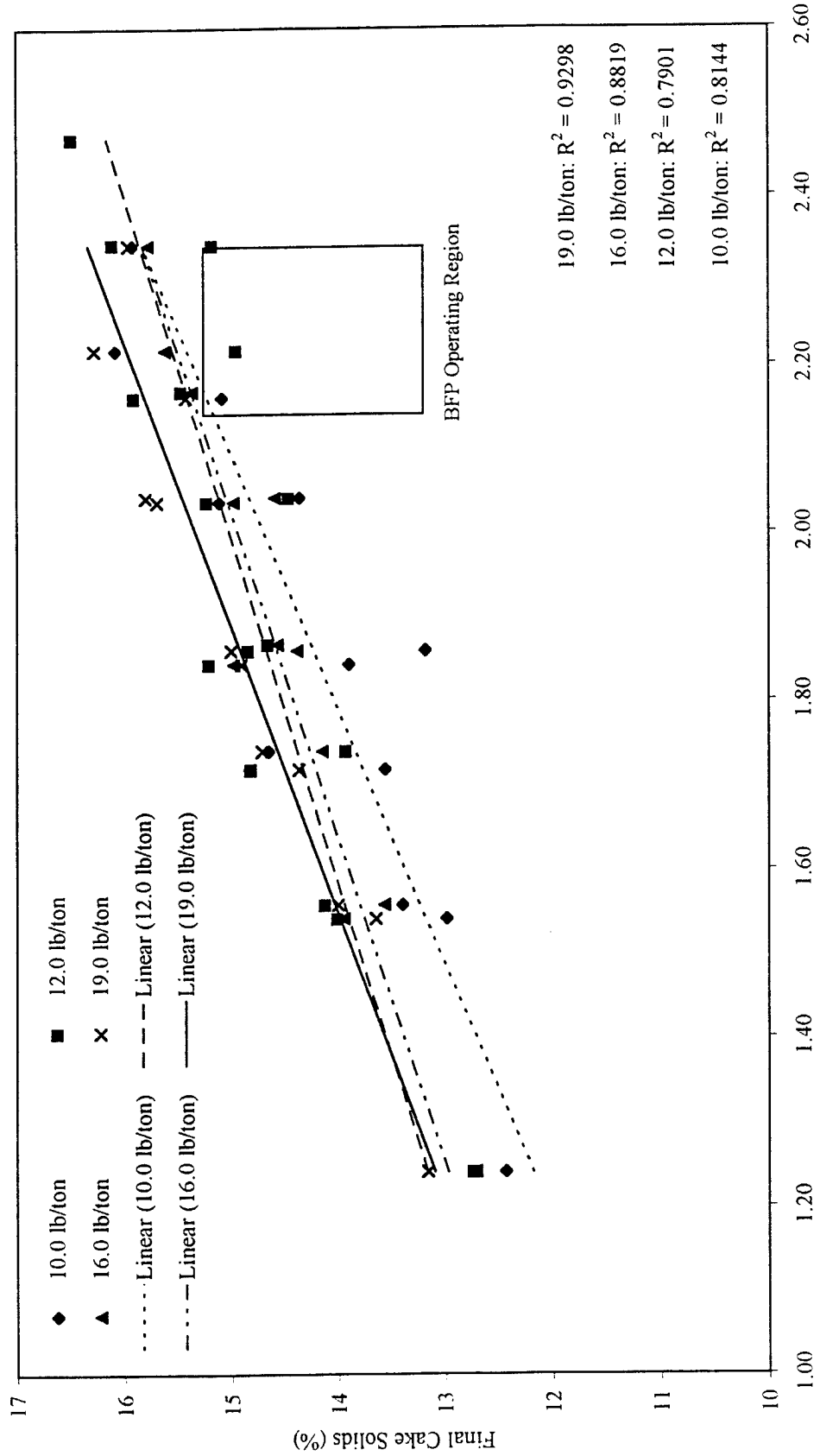


Figure 4.22 Crown Press polymer evaluation test for sludge conditioned with Percol 778 FS25 using a 0.50% polymer solution.

4.6 Evaluation of Belt Fabrics

The belt material used on a BFP is another operating parameter that can affect the overall performance of the dewatering equipment. To test the effect of various belt fabrics on the dewatering of Mauldin Road's WAS, four different belt types were used in identical press tests to dewater sludge conditioned with ES 1598 at 10.14 lb/ton. The results of these four sets of press tests were compared to an identical set of tests performed with Mauldin Road's belt material and are shown in Figure 4.23. Three pressures were used in each test for four time intervals.

The highest pressure tested on four of the five belts was 3.66 psi. Above this pressure, the amount of solids in the belts became excessive and blinding was severe. The highest pressure used on the fifth belt, IF 6912, was 2.41 psi due to sludge squeezing through the belt weave at 3.66 psi. This belt material had a more open weave than the other belts tested, which contributed to the ease with which the sludge penetrated the belt. The linear regression fits for two of the belts tested, IF 6461 and #1 from Company X, intersected the middle part of the BFP operating region. Because IF 6912 could not be tested above 2.41 psi, the log(pressure*time) values were not high enough to intersect the operating region. The remaining linear regression fit for belt material #2 from Company X intersected the lower end of the operating region. This evaluation of belt materials was not meant to include all of the different types of belt material or manufacturers. These results simply demonstrated that the belt material currently being used on the BFPs is better suited for dewatering this type of sludge than the three other belt types tested.

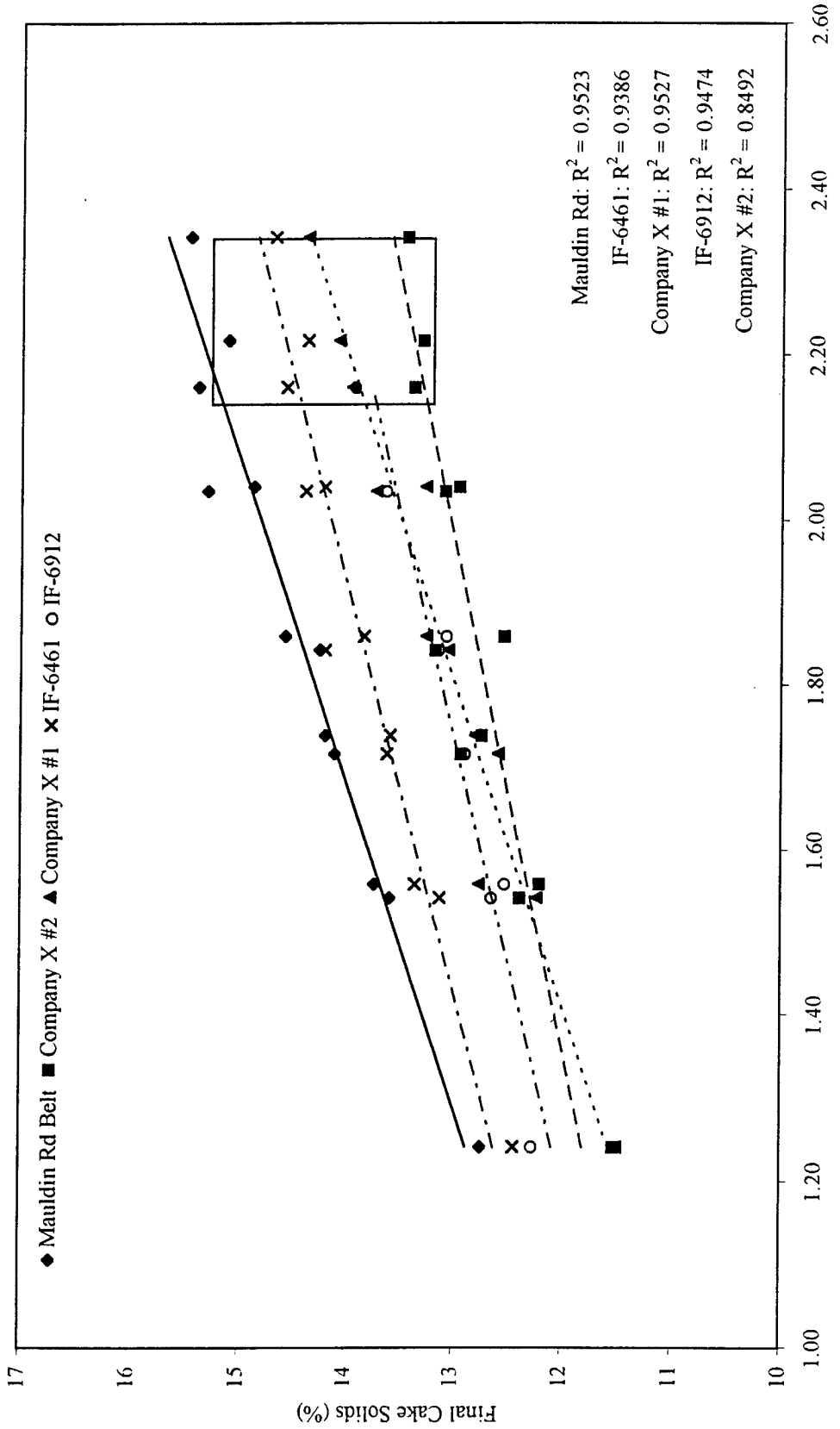


Figure 4.23 Crown Press evaluation of belt fabric using sludge conditioned with ES 1598 at 10.14 lb/ton.

4.7 Evaluation of Metals Addition

As was discussed in Chapter 2, the presence of specific monovalent and divalent cations affects the potential dewaterability of some sludges. Using the conclusions drawn by Higgins and Novak (1996), the addition of magnesium and calcium to the Mauldin Road WAS was investigated. Influent sludge with and without magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$) added to it were conditioned with ES 1598 according to the procedures outlined in Chapter 3. Three polymer doses were evaluated using CST and SRF, and two doses were tested on the Crown Press. All of the sludge was conditioned with an ES 1598 polymer solution. Figure 4.24 shows the results of the CST and SRF tests. For the three polymer doses used in the CST and SRF tests, the impact of the added cations was more noticeable in the SRF results than in the CST results. The capillary suction times were similar for sludge with and without metals conditioned at 6.10 and 10.16 lb/ton. However, there was a clear distinction in the average CST values for the two sludges conditioned at 14.23 lb/ton. The sludge with $MgCl_2$ and $CaCl_2$ added had an average CST value almost 14 seconds lower than the sludge without metals. The SRF results in Figure 4.24b show a definite improvement in potential dewaterability. At 6.10 lb/ton and 14.23 lb/ton the SRF value decreased by over 40% and 70%, respectively, when magnesium and calcium were added to the sludge. At 10.16 lb/ton, the SRF values with and without metals added were approximately the same. These results suggested that addition of metals could improve WAS dewaterability, depending on the polymer dose used.

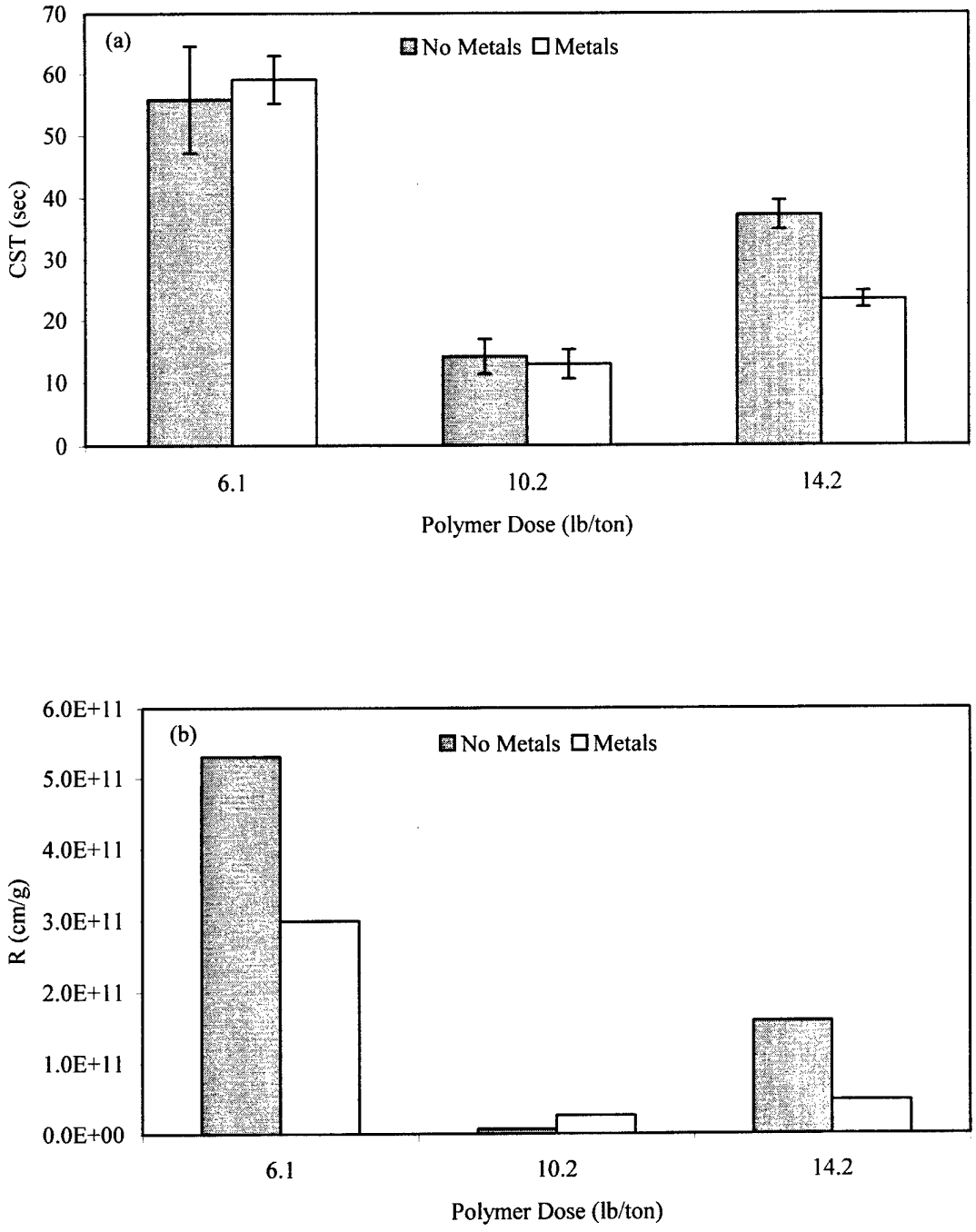


Figure 4.24 (a) CST and (b) SRF tests comparing $MgCl_2$ and $CaCl_2$ enhanced sludge to normal influent sludge. ES 1598 was used for sludge conditioning. CST error bars represent ± 1 standard deviation of sample average.

The prediction made by CST and SRF results was tested on the Crown Press with two polymer doses. $MgCl_2$ and $CaCl_2$ were added to a 2-L sludge sample at the same concentration used in the CST and SRF tests. This sample was then mixed for 30 minutes at 200 rpm. To eliminate any variations that could occur due to the actual mixing of the sludge, a second 2-L sample of sludge without metals added to it was also mixed under the same conditions. From these 2-L samples, 300 mL of sludge was mixed with the appropriate amount of ES 1598 polymer solution to achieve the tested polymer dose. The two polymer doses, 8.82 and 11.02 lb/ton, were pressed at 1.16 and 2.41 psi for 30 and 60 seconds each. Figure 4.25 shows the linearized data for the four sets of tests. The linear fits for the conditioned sludge without metals intersected the BFP operating region, which was expected for LCS with ES 1598. Considerably higher final cake solids concentrations were obtained with the cation-enhanced sludge. These cake solids were an average of 1.8% solids higher than the cake solids for the sludge without the addition of $MgCl_2$ and $CaCl_2$.

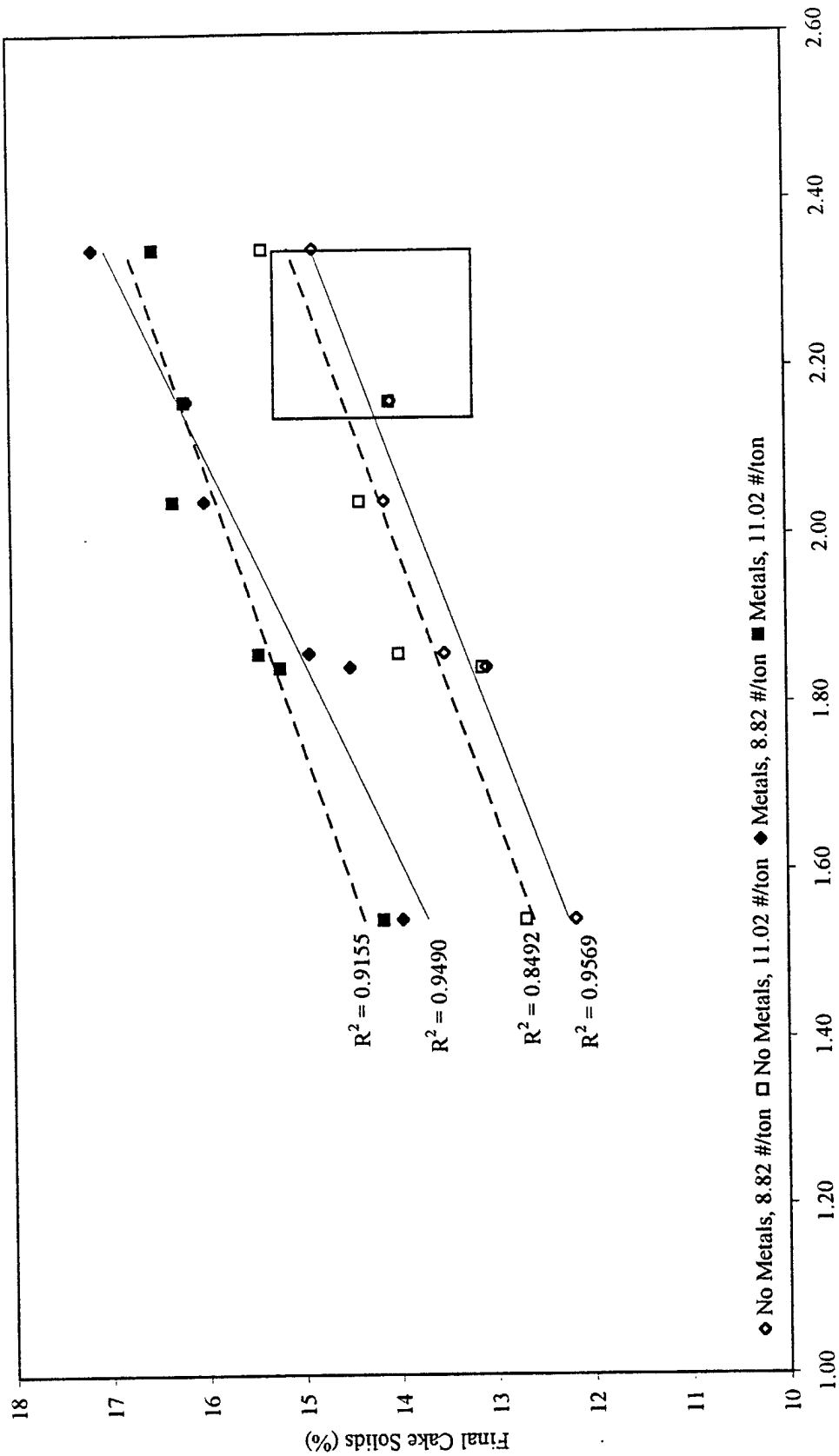


Figure 4.25 Crown Press evaluation of ES 1598 LCS with and without $MgCl_2$ and $CaCl_2$ added to the sludge.

The Crown Press results indicated that the addition of the Mg^{2+} and Ca^{2+} improved the conditioning of the sludge such that higher cake solids could be achieved with the same polymer at the same dose as is currently used. This also suggests that a lower polymer dose could be used to obtain the same final cake solids in the presence of these divalent cations. The first option require the additional expense of a magnesium and calcium salt without any decrease in polymer use. The second option would require the purchase of the divalent salts, but would decrease the polymer demand and therefore polymer costs. These results agree with the findings of Higgins and Novak (1996). Their studies found that when Mg^{2+}, in the form of $Mg(OH)_2$, was added to the mixed liquor in order to increase the concentration of divalent cations, polymer requirements for dewatering decreased and final cake solids improved.

4.8 Full-Scale Evaluation

The final stage of this project involved testing several of the predictions made with laboratory results on BFPs at the Mauldin Road facility. The two BFP tests involved lowering the belt speed and changing the polymer. The final cake solids obtained during each BFP test were compared to cake solids obtained on a BFP operating under normal conditions.

4.8.1 Plant Data Analysis

Each day the BFPs are operating at the Mauldin Road facility, samples of final cake are analyzed for cake solids at least two times during the course of operation. As stated earlier, the operators use a microwave analyzer to determine these concentrations. Data from January to December 1997 was collected in order to compare the performance

of all four presses. The presses were only compared on days in which the given presses were operating together (i.e. Presses #1 and #4 were only compared using data from the days when both were used). Table 4.7 summarizes the comparisons of all the presses. All of the data is presented as the average final cake solids concentration for the given press. These comparisons show that all of the presses perform differently from all of the other presses, with the exception of Presses #2 and #4. The largest difference was between Presses #1 and #4, in which Press #1 achieved on average over 1% higher cake solids than Press #4. The results of these analyses were used to interpret the results of the plant polymer tests, which are provided below.

Table 4.7 BFP performance comparison using 1997 data.

Press #1	Press #2	Press #3	Press #4	t-test result	Difference
15.042	14.182			sig. diff.[1]	0.860
14.928		14.215		sig. diff.[1]	0.713
15.141			14.083	sig. diff.[1]	1.058
	13.924	14.282		sig. diff.[1]	0.358
	14.075		14.096	no sig. diff.[2]	-
		14.111	13.867	sig. diff.[1]	0.244
15.098	13.939	14.311	14.011	sig. diff.[1]	-

[1]There was a significant difference between the population means, as indicated by $t_{calculated} > t_{critical}$.

[2]There was no significant difference between the population means, as indicated by $t_{calculated} < t_{critical}$.

4.8.2 Belt Speed Tests

The belt speed tests were conducted according to the procedures outlined in section 3.12.1. During the testing, the sludge loading was adjusted according to the sludge loading factor to match the loading factor of the parallel press. After setting the sludge and polymer pumps to the appropriate speeds to achieve the proper sludge loading factor as dictated by the belt speed, the sludge was monitored to ensure proper conditioning. Typically, adjustments were necessary to get the proper polymer dose which would alter the sludge loading factor. In all cases, the changes decreased the sludge loading factor below that of the comparison press.

During the first belt speed tests the sludge loading rate on Press #4 was 1065 lb/hr and the polymer dosage was 14.13 lb/ton. The belt speed was lowered twice during the course of the test, once from 25.3 ft/min to 18.5 ft/min and then from 18.5 ft/min to 13.8 ft/min. In both cases the sludge loading was not adjusted. The results from this test are shown in Table 4.8. The overall average cake solids at the three belt speeds tested were 14.04%, 13.73%, and 13.48% solids, respectively. These results indicated that without an adjustment to the sludge loading rate, lower belt speeds caused lower cake solids. This is due to the thickness of the sludge cake between the belts being too large to allow effective dewatering in the shear zone of the BFP.

Table 4.8 Belt speed testing on Press #4 without sludge loading adjustment.

Sample #	Final Cake Solids (%)*	Belt Speed (ft/min)
1a	14.09	25.3
1b	13.64	25.3
2a	13.56	25.3
2b	14.55	25.3
3a	14.70	25.3
3b	13.68	25.3
Average (1-3)	14.04	25.3
4a	13.11	18.5
4b	14.06	18.5
5a	13.60	18.5
5b	14.14	18.5
Average (4-5)	13.73	18.5
6a	12.50	13.8
6b	14.36	13.8
7a	12.87	13.8
7b	13.18	13.8
Average (6-7)	13.48	13.8

*Oven analyzed

Two other belt tests were also conducted on Press #4. The initial speed of the belts during the second test was 24.6 ft/min, the polymer dose was 11.1 lb/ton, the loading factor was 0.810 lb/ft, and the average cake solids prior to adjusting the belt speed were 14.43% solids. It is important to note that these cake solids were determined at the plant by microwave analysis and are therefore approximately 1.2% higher than what oven dried analysis would determine. The belt speed was first decreased to 18.2 ft/min and the sludge loading rate was set at 860 lb/hr, giving a sludge loading factor of 0.787 lb/ft. The belt speed was decreased again to 12.5 ft/min and the sludge loading rate was decreased to 675 lb/hr, giving a sludge loading factor of 0.900 lb/ft. During both

adjustments, the polymer pump speed was changed to maintain a dose between 10 and 11 lb/ton. The oven-analyzed cake solids for these samples are shown in Table 4.9. The average cake solids for these two belt speeds were 13.06% solids and 12.81% solids, respectively.

The third test used a belt speed of 12 ft/min and two sludge loading rates, 763 and 700 lb/hr. Press #4 was not operating prior to the start of the test, so the press was started at the lower belt speed and 760 lb/hr loading rate. The polymer dose was set at 12 lb/ton to achieve proper conditioning of the sludge. The sludge loading rate was then decreased to 700 lb/hr, while maintaining a constant belt speed and polymer dose. The sludge loading factors for the two conditions were 1.06 and 0.97 lb/ft. Three samples were taken during each operating condition and were oven analyzed for solids content. The average cake solids were 13.32% for 1.06 lb/ft and 13.54% for 0.97 lb/ft, shown in Table 4.9.

Table 4.9 Belt speed testing on Press #4 with sludge loading adjustment.

Sample #	Belt Speed, ft/min	Solids Loading Rate, lbs/hr	Solids Loading Factor, lbs/ft	Final % Cake Solids (Oven Analyzed)
1-1	18.2	860	0.788	12.98
1-2	18.2	860	0.788	13.34
1-3	18.2	860	0.788	12.85
Average:	18.2	860	0.788	13.06
1-4	12.5	675	0.900	12.44
1-5	12.5	675	0.900	12.85
1-6	12.5	675	0.900	12.54
1-7	12.5	675	0.900	13.28
1-8	12.5	675	0.900	12.96
Average:	12.5	675	0.900	12.81
2-1	12	763	1.06	13.57
2-2	12	763	1.06	13.30
2-3	12	763	1.06	13.08
Average:	12	763	1.06	13.32
2-4	12	700	0.972	13.15
2-5	12	700	0.972	13.67
2-6	12	700	0.972	13.80
Average:	12	700	0.972	13.54

Overall, these results suggest that decreasing the belt speed to increase time under pressure, even at a decreased loading, does not increase final cake solids. An improvement may have been possible at a solids loading factor closer to that of normal operation (i.e. 0.810 lb/ft). However, this low a solids loading rate is impractical from an operational standpoint, since the rate of sludge processing would be far too low.

These belt speed BFP tests were analogous to altering the times under pressure for the Crown Press tests. In all of the laboratory tests, the general trend was that as the time under pressure increased, the cake solids increased. However, this was not the case on the BFPs. As was shown above, lower belt speeds (i.e. long times under pressure) did not result in higher cake solids. Because each Crown Press test used the same amount of

sludge, which is analogous to the sludge loading rate on the BFP, the loading rate to the BFPs was adjusted as the belt speed was decreased. Even with this change, the cake solids did not increase. These findings suggest that there are other factors contributing to the lack of improvement in cake solids as the time under pressure increased. One of these factors may be the poor quality of the belts after in-line cleaning, which leaves a large amount of solids in the belt weave. The solids that are not removed from the belt hinder the separation of released water and filtrate from the sludge cake, causing the sludge cake to have a higher moisture content and a lower solids content.

4.8.3 Polymer Tests

The final plant tests conducted on the BFPs at the Mauldin Road facility involved changing the polymer used to condition the sludge. Prior to beginning testing with different polymers, final cakes and filtrate samples were collected from Presses #1, 3, and 4 over an entire day of operation. The average operational parameters for the three presses on this day are presented in Table 4.10. The influent sludge and the polymer solution had an average solids concentration of 3.01% and 0.44%, respectively. These samples were used to establish the presses' normal performance at the time of the polymer trials. A comparison of the final cake solids (oven analyzed) between presses #1 and #3, #1 and #4, and #3 and #4 showed that the relative performance of the presses was generally the same as the long-term relative performance of the presses (Table 4.7). The difference in performance of Presses #1 and #3 was less than the long-term difference, as was the case with Presses #1 and #4. The difference between the performance of Presses #3 and #4 was actually higher than the long-term difference. Unfortunately, Press #2 was

not operating on this day, therefore its relative performance could not be established at the beginning of the polymer trials. It is also important to recognize that the average cake solids for all four presses were lower throughout the trials than the long-term averages presented in Table 4.7. Thus, the relative performance of the presses became more important than the actual cake solids achieved.

The two polymers chosen for plant evaluation were Percol 775 FS25 and Superfloc SD 2085. The first was chosen because its lab performance was similar to the performance of ES 1598, as indicated by the range of cake solids obtained with Percol 775 FS25. Also, the supplier claimed that Percol 775 FS25 would work better than ES 1598 because it is specifically designed for WAS. Superfloc SD 2085 was chosen because its performance far exceeded the typical cake solids achieved with ES 1598. These two polymers would allow a clear evaluation of the laboratory predictions in comparison to BFP performance.

Table 4.10 BFP average operating parameters on 3/23/98.

Parameter	Press #1	Press #3	Press #4
Indicator Belt Speed, ft/min	20.5	20.5	23.2
Polymer Pump % Speed	50%	55%	46%
Polymer Flowrate, GPM	3.33	3.67	3.07
Sludge Flowrate, GPM	82	63	68
Sludge Loading Rate, lbs/hr	1231	946	1021
Polymer Dosage, lbs/ton	12.47	17.08	13.24
Final Cake Solids, %*	12.75 ± 0.27	12.36 ± 0.76	11.95 ± 0.48
Pressate TSS, mg/L	108 ± 21	279 ± 111	35 ± 2

*± = 1 standard deviation of the sample average.

The first polymer evaluated was Percol 775 FS25. This polymer was used to condition sludge on all four presses over a three-day period. During the first day of testing Percol 775 FS25 was used on Press #1 and the plant's ES 1598 was used on Presses #3 and 4. On the second day, Percol 775 FS25 was used on Presses #3 and 4 and ES 1598 was used on Press #1. Press #2 was not operating on either of these days due to a malfunction in the sludge pump motor. At the end of the second day of testing, the drive shaft on Press #1 failed. This removed Press #1 from all further tests due to the estimated repair time of one month. Because only three samples were taken while Percol 775 FS25 was being used on Press #1, a third day of testing was necessary to increase the sample size of cake solids produced with this polymer. Percol 775 FS25 was used on Press #2, while ES 1598 was used on Press #3 during the third day of testing. Table 4.11 presents the results of these three days of testing with Percol 775 FS25.

Table 4.11 Results of Percol 775 FS25 testing on BFPs at the Mauldin Road facility.

Date	Press #	Polymer Used	Average Polymer Dosage, lbs/ton	Average Final Cakes Solids*, %	Pressate TSS, mg/L
3/24/98	1	Percol 775 FS25	14.59	12.21 ± 0.17	60 ± 23
	3	ES 1598	17.55	12.59 ± 0.83	51 ± 30
	4	ES 1598	11.55	12.05 ± 0.28	20 ± 11
3/25/98	1	ES 1598	8.71	12.98 ± 0.45	37 ± 28
	3	Percol 775 FS25	17.02	12.02 ± 0.66	175 ± 102
	4	Percol 775 FS25	12.87	11.76 ± 0.39	85 ± 54
3/30/98	2	Percol 775 FS25	24.07	12.11 ± 0.37	46 ± 31
	3	ES 1598	12.12	12.41 ± 0.90	46 ± 33

*Oven analyzed.

On the third day of testing with Percol 775 FS25, the polymer dose was substantially higher than the previous two days. The goal of this was to determine if a higher polymer dose would result in higher cake solids, which it did not. Table 4.12

presents a comparison between the performance of ES 1598 and Percol 775 FS25 based on the data in Table 4.7. The "Press Difference" column represents what the typical difference in cake solids is between the two presses being compared. For example, the first row compares press #3 with ES 1598 to press #1 with Percol 775 FS25. Under normal operating conditions, the cake solids from press #3 were 0.71% solids lower than the cake solids from press #1. During this test however, the cake solids from press #3 were 0.38% solids higher than the cake solids from press #1. This means that Percol 775 FS25 actually under performed what is typically expected when comparing press #3 to press #1 by 1.1% solids. The overall average adjusted difference in the performance of Percol 775 FS25 as compared to ES 1598 was almost 0.50% solids lower than the typical performance of the presses.

Table 4.12 Relative performance of Percol 775 FS25 to ES 1598.

Date	Presses	(A) ES 1598	(B) Percol 775 FS25	B-A	Press Difference*	Adjusted Difference
3/24/98	3 vs. 1	12.59	12.21	-0.38	-0.71	-1.1%
	4 vs. 1	12.05	12.21	0.16	-1.06	-0.90
3/25/98	1 vs. 3	12.98	12.02	-0.96	0.71	-0.25
	1 vs. 4	12.98	11.76	-1.22	1.06	-0.16
3/30/98	3 vs. 2	12.41	12.11	-0.30	0.36	0.06
Average:						-0.47

*From Table 4.7.

Referring to the laboratory results for Percol 775 FS25 in section 4.5.5, the Crown Press tests predicted that the performance with this polymer would be similar to that of ES 1598. Even at the highest polymer dose tested in the lab (19.2 lb/ton), the cake solids were not higher than the typical operating region for the BFPs. The results from the

testing on the BFPs agree with these predictions. Although the cake solids were lower across the board than those produced in the lab, the relative performance shows that at the time of the plant testing Percol 755 FS25 performed as predicted.

The second polymer tested on the BFPs was Superfloc SD 2085. This polymer was tested on three consecutive days on Presses #2, 3, and 4. As was stated above, Press #1 was not operating during the tests. On the first day of testing, SD 2085 was used on Press #2 and ES 1598 was used on Press #3. SD 2085 was then tested on Presses #3 and 4 on the second day, while ES 1598 was used on Press #2. At the end of the second day of testing, there was enough SD 2085 solution remaining to run a third day of tests. This allowed SD 2085 to be tested again on Press #2, but at a higher polymer dose than was used on the first day. ES 1598 was used on Press #3. Table 4.13 presents the results of these three days of testing with Superfloc SD 2085.

Table 4.13 Results of Superfloc SD 2085 testing on BFPs at the Mauldin Road facility.

Date	Press #	Polymer Used	Average Polymer Dosage, lbs/ton	Average Final Cakes Solids*, %	Pressate TSS, mg/L
4/1/98	2	Superfloc SD 2085	14.21	13.59 ± 0.42	21 ± 16
	3	ES 1598	16.34	13.05 ± 0.70	46 ± 16
4/2/98	2	ES 1598	9.92	13.16 ± 0.17	19 ± 8
	3	Superfloc SD 2085	16.47	13.09 ± 0.51	52 ± 32
	4	Superfloc SD 2085	17.03	13.28 ± 0.57	122 ± 55
4/3/98	2	Superfloc SD 2085	20.9	13.73 ± 0.51	57 ± 39
	3	ES 1598	10.13	12.31 ± 0.77	56 ± 12

*Oven analyzed.

On the third day of testing the SD 2085 polymer dose on press #2 was increased to the approximate dose which produced the highest cake solids in the lab (Figure 4.13). The results show that this dose produced the highest average cake solids of any press on

all three days of testing. Also, SD 2085 performed better at the higher dose without a significant change in pressate TSS. Table 4.14 presents a comparison between the performance of ES 1598 and SD 2085 based on the data in Table 4.7. The format of Table 4.14 is the same as that of Table 4.12. For example, the first row compares press #3 with ES 1598 to press #2 with SD 2085. Under normal operating conditions, the cake solids from press #3 were 0.36% solids higher than the cake solids from press #2. During this test however, the cake solids from press #3 were 0.55% solids lower than the cake solids from press #2. This means that SD 2085 over performed what is typically expected when comparing press #3 to press #2 by 0.91% solids. The other test in which SD 2085 significantly over performed ES 1598 was on 4/3/98, when SD 2085 was used on press #2 at a higher polymer dose. The overall average adjusted difference in the performance of SD 2085 as compared to ES 1598 was 0.60% solids higher than the typical performance of the presses. Although the cake solids for all four presses during these plant tests were lower than the long-term averages, the relative comparisons between presses show that SD 2085 did improve the performance of the BFPs. The prediction of better performance with SD 2085 by the Crown Press was therefore demonstrated on the BFPs in two of the four tests presented in Table 4.14.

Table 4.14 Relative performance of Superfloc SD 2085 to ES 1598.

Date	Presses	(A) ES 1598	(B) SD 2085	B-A	Press Difference*	Adjusted Difference
4/1/98	3 vs. 2	13.05	13.59	0.55	0.36	0.91
4/2/98	2 vs. 3	13.16	13.09	-0.07	-0.36	-0.43
	2 vs. 4	13.16	13.28	0.12	0	0.12
4/3/98	3 vs. 2	12.31	13.73	1.42	0.36	1.75
Average:						0.60

*From Table 4.7.

Another important aspect of the plant testing was verification of the Crown Press results with PCS from the polymer tests. During polymer testing on three separate days, conditioned sludge was collected from the front of the gravity drainage zone on Press #2 as the sludge fell out of the flocculator. On the first day, the sludge was conditioned with Percol 775 FS25 at an average polymer dose of 24.07 lb/ton. On the second and third days, Superfloc SD 2085 was being used to condition sludge on Press #2 at dosages of 14.21 and 20.9 lb/ton, respectively. These conditioned sludge samples were taken back to the laboratory for testing on the Crown Press. Each sludge sample was pressed at 1.16, 2.41 and 3.66 psi for 30 and 60 seconds. The results of these press tests are shown in Figure 4.26. The linear regressions for both the Percol 775 FS25 and the lower dose SD 2085 intersected the BFP operating region. The linear regression for the higher dose SD 2085 sludge sample fell above the operating region. In all three tests, the Crown Press produced dewatered cakes with solids concentrations slightly higher than the average cake solids achieved on the BFPs during the polymer testing, but the trend in the Crown Press data remained the same as the trend in the plant data.

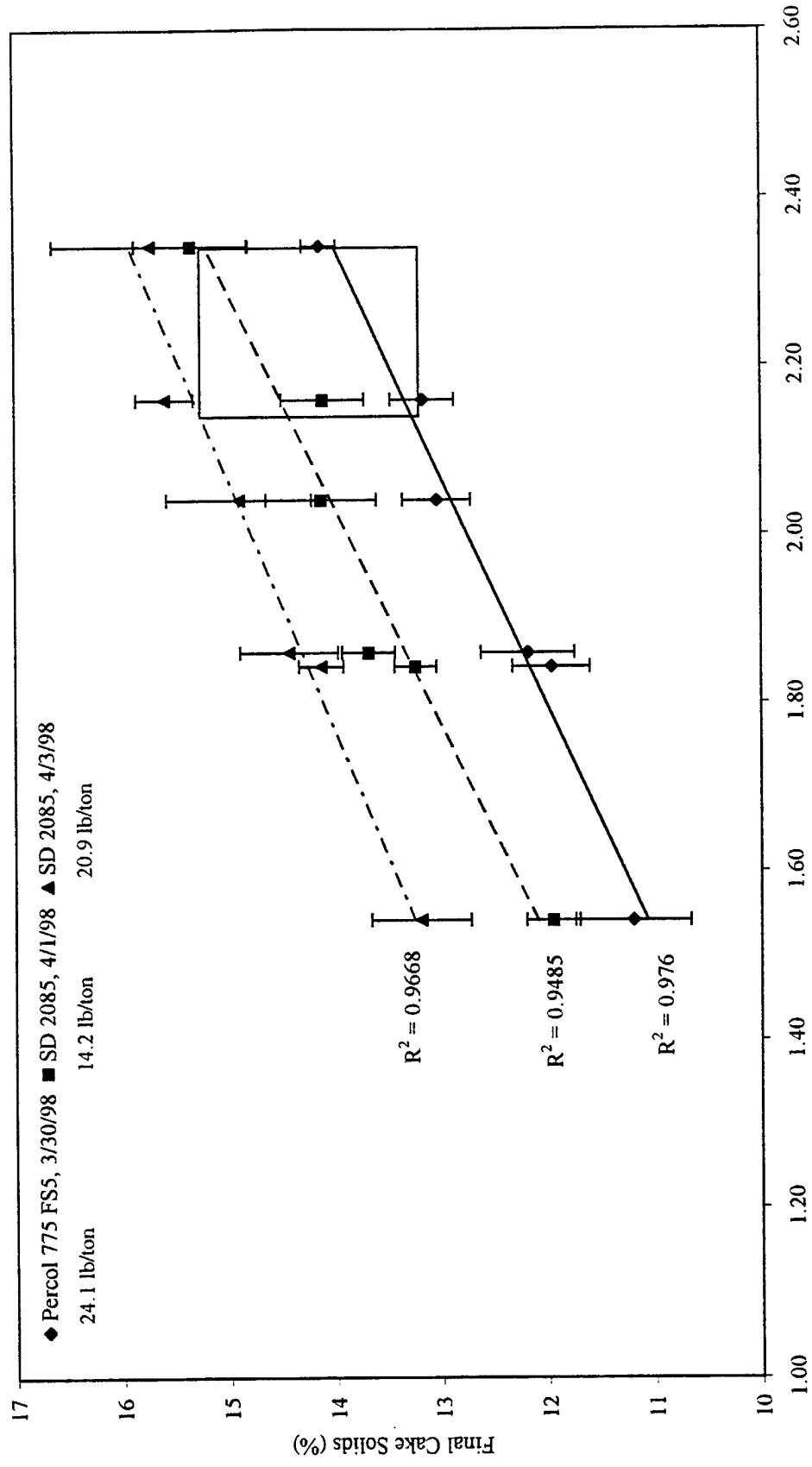


Figure 4.26 Crown Press evaluation of PCS collected during polymer testing. Error bars represent +/- 1 standard deviation of sample average.

4.9 Plant Survey

Several plants were contacted that are using BFPs to dewater undigested WAS. None of the plants were biological phosphorus removal facilities and all of the plants were significantly smaller than the Mauldin Road plant. This survey, shown in Table 4.15, was done to determine if the performance of the BFPs at the Mauldin Road plant were typical for other plants dewatering WAS. Because the sample size is rather small, no significant conclusions can be drawn concerning the relative performance of Mauldin Road's BFP operation to a general trend at other wastewater treatment plants.

Table 4.15 Plant survey results.

WWTP Surveyed	Type of plant	% Industrial	Sludge age	Type of Polymer	Polymer Dosage (lb/ton)	Influent % solids	Final % Cake Solids
Seabrook, NH	Activated sludge, 0.6 MGD	8-10	8-15 days	Dry, high molecular cationic	16-18	1	15-20
Collier County, FL	Activated sludge, 8.5 MGD	Light load	1-5 days (?)	Emulsion, Percol 778 (Allied Colloids)	10.8	1.5-2.5	16.5 (current) 17.4 ('96 average)
Eastman Plant, Kingsport, TN	Conventional activated sludge	100	12-18 days	Cationic and bentonite clay	?[+]	1.8-2.2	12.5
Walton, NY	Activated sludge, extended aeration, 1.17-1.3 MGD	50 (dairy)	?	Liquid, Stockhausen Stayfloc 250	?	4	18-22
Liberty, NY	Oxidation ditch, $FeSO_4$ for P removal	?	?	ECE microbead, cationic	?	3	19-20
City of Edmonds, WA	Activated Sludge with incineration	?	?	?	9	1.3*	20.9 ('96 average)
WCRSA, Mauldin Rd.	Biological P removal, 20 MGD	20	8 days	ES 1598, dry	10-14	3.5	14

*Feed to BFPs is 60% WAS and 40% primary sludge.
[+]? indicates that this information was not provided by the contact person at the plant.

CHAPTER 5

DISCUSSION

This discussion will focus on four issues. First, a comparison of CST and SRF tests to the Crown Press test for the different polymers examined in the project is important in understanding how these tests can be interpreted as predictive tools. Second, the importance of pressure in both Crown Press and BFP dewatering and the problems with testing pressure changes on the BFPs are discussed. Third, the difficulty of translating the results obtained either in the lab or at the plant with different polymers into a cost-benefit relationship is discussed. Fourth, the potential benefits of using cation adjustment to improve dewaterability are presented. The final issue presented is the benefit of using a high-pressure hot water spray to provide additional cleaning of the belts after the dewatered cake has been removed.

5.1 CST, SRF and Crown Press Comparison

CST and SRF are widely used tools to measure the potential dewaterability of conditioned sludge. Several authors (Barber et al., 1997; Christensen et al, 1993; Vesilind, 1988; Knocke and Novak, 1987; Poduska and Stroupe, 1980; Karr and Keinath, 1978;) however, have presented either difficulties encountered using CST and SRF or modified versions of these tests. In light of these others studies, the CST and SRF results presented in Chapter 4 were analyzed with respect to the Crown Press results and the plant testing results. The CST and SRF measurements for the three polymers used in the plant tests are shown in Figures 5.1 and 5.2. All three polymers achieved relatively

similar minimum CST values, only at different polymer doses. Percol 775 FS25 had the lowest SRF value of 1.37e10 cm/g at a polymer dose of 15.6 lb/ton, and ES 1598 had the highest SRF value of 3.53e10 cm/g at a polymer dose of 9.08 lb/ton. Table 5.1 shows the minimum CST and SRF values for the three polymers presented in Figures 5.1 and 5.2 and the dose at which these minimum values were obtained.

Table 5.1 Minimum CST and SRF values.

	CST		SRF	
Polymer	**Minimum Value, sec**	**Polymer Dose, lb/ton**	**Minimum Value, cm/g**	**Polymer Dose, lb/ton**
ES 1598	13.1	9.08	3.53E10	9.08
Superfloc SD 2085	11.7	17.5	2.27E10	14.6
Percol 775 FS25	12.6	17.9	1.37E10	15.6

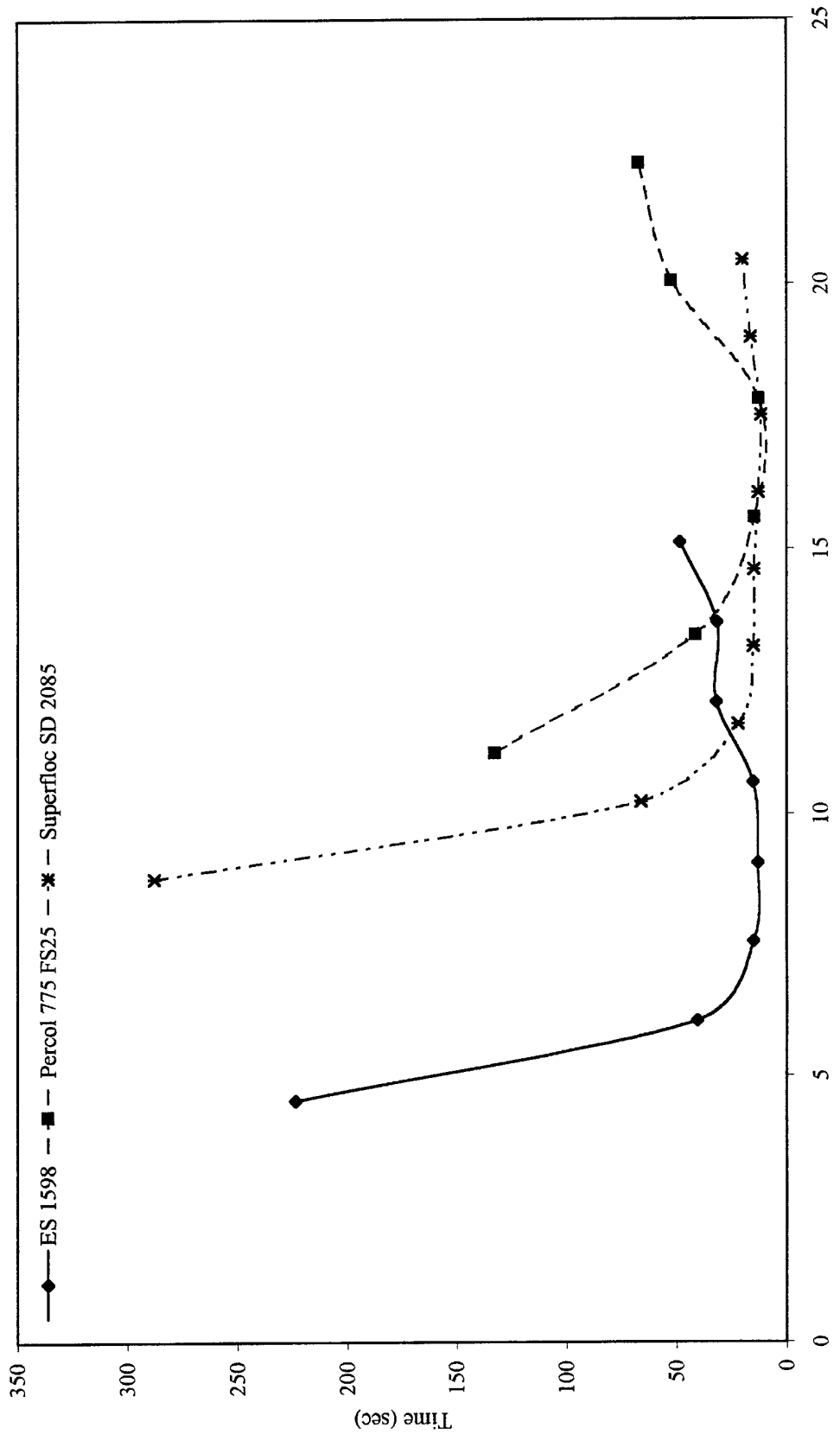


Figure 5.1 Comparison of CST results for the three polymers used during plant testing.

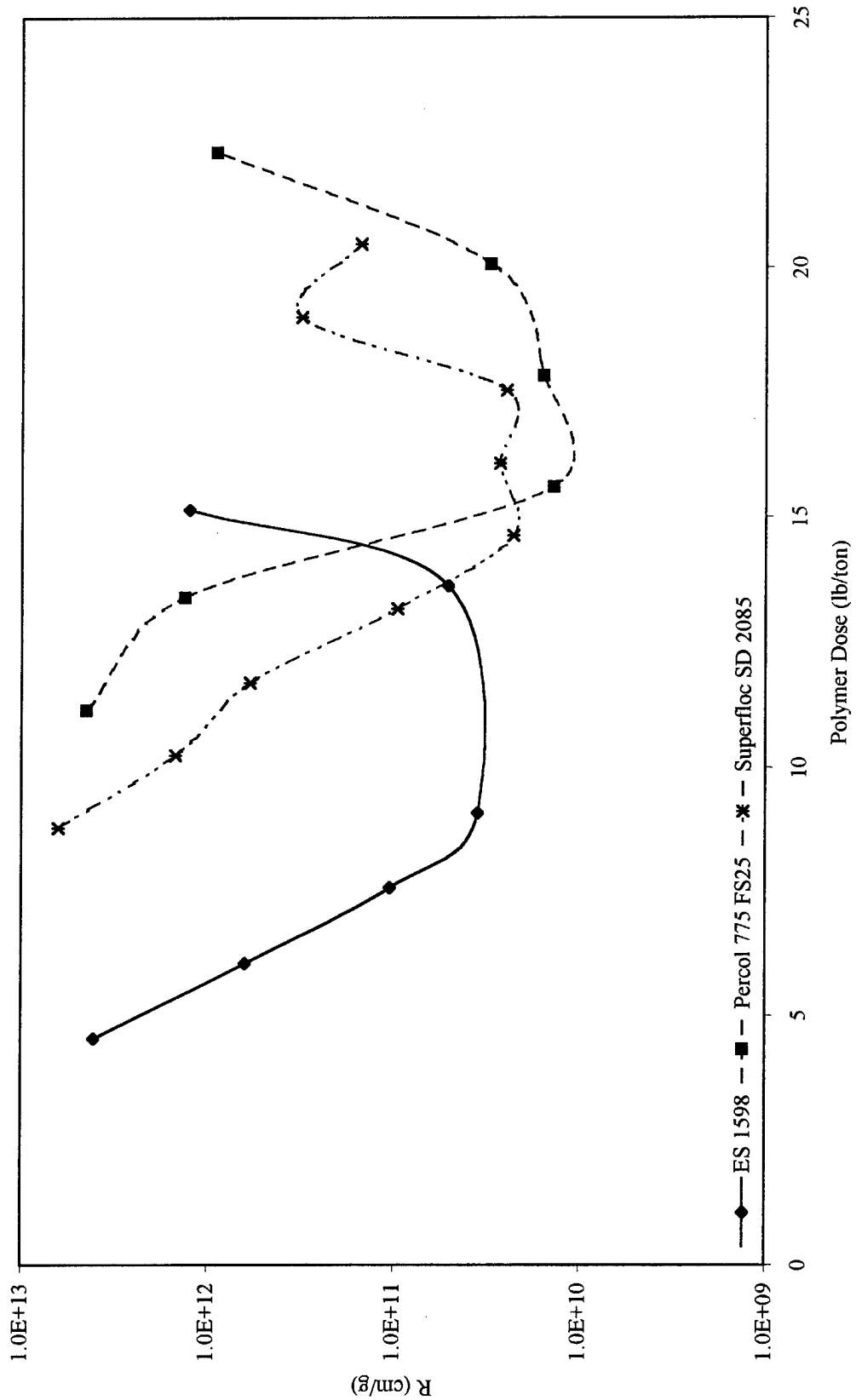


Figure 5.2 Comparison of SRF results for the three polymers used during plant testing.

The first prediction that could be made based on these results is that Superfloc SD 2085 and Percol 775 FS25 should require a higher polymer doses than ES 1598 to achieve effective dewatering. The plant tests verified this prediction. During plant tests, the average polymer dose on the first two days of testing Superfloc SD 2085 was 15.9 lb/ton, and on the third day the polymer dose was 20.9 lb/ton. The average polymer dose for Percol 775 FS25 on the first two days it was tested on the BFPs was 14.8 lb/ton. The highest dose tested was 24.1 lb/ton. These doses are higher than the typical polymer dose of 10-14 lb/ton used on the BFPs for ES 1598. The average ES 1598 dose throughout the plant testing was 12.3 lb/ton, which is over 2.5 lb/ton lower than the average doses used for Superfloc SD 2085 and Percol 775 FS25.

The next prediction that could be made is the range of polymer doses that should achieve effective dewatering. For Superfloc SD 2085, effective dewatering should occur between 14 and 17 lb/ton, based on the minimum values for CST and SRF. For Percol 775 FS25, the range of effective polymer doses should be 15 to 18 lb/ton. The average polymer doses during the plant tests listed above for these polymers are within these ranges. However, during the Crown Press tests the lowest doses that produced a pressable cake for Superfloc SD 2085 and Percol 775 FS25 were 13.2 lb/ton and 12.6 lb/ton, respectively. These doses are lower than the doses that produced the minimum CST and SRF values. The doses that produced the highest cake solids on the Crown Press for these two polymers were 21.6 lb/ton and 19.2 lb/ton, respectively. Based on the CST and SRF results, these doses should have resulted in deteriorated dewatering, but they did not. These results suggest that the range of doses indicated by CST and SRF that should be used for effective dewatering is too narrow. The results of the Crown Press

tests show that pressable conditioned sludge can be achieved at doses above and below the CST and SRF predicted range.

On the last day of tests with both Superfloc SD 2085 and Percol 775 FS25, the polymer doses were increased above the range predicted by CST and SRF to the approximate doses used in the lab that resulted in the highest cake solids. The Percol 775 FS25 dose used was 24.1 lb/ton on Press #2. Unfortunately, this press was not operating on the day that the initial sludge cake samples produced with ES 1598 were taken for comparison purposes. Therefore, no conclusions can be drawn concerning the effect of a higher dose on cake solids. However, the results of Superfloc SD 2085 at a dose of 20.9 lb/ton can be compared to the previous days of testing (Table 4.12). The average cake solids during this day was clearly higher than the cake solids achieved on any other day. These results show that the higher polymer dose did not decrease dewaterability and, in fact, contributed to increased cake solids. If the results of the CST and SRF tests were the only predictors used to gauge the BFP polymer dose, these upper doses would more than likely not be tested.

The CST and SRF results from the five polymers evaluated indicated that all of them would be suitable for potentially dewatering the WAS, when compared to the CST and SRF results for ES 1598, only at higher polymer doses. Had the results from these tests been used to choose the polymers to be tested on the BFPs, there would have been no way to distinguish between the five polymers. This would have left the plant the choice of either testing all five, which would be very time consuming and potentially expensive, or choosing a few of the polymers to test, which could result in eliminating the polymer that would have actually improved BFP performance. By using the Crown

Press, the polymers that did not improve the final cakes in the lab were eliminated, thus decreasing the amount of time required for plant testing and increasing the likelihood of finding a polymer that would improve BFP performance.

5.2 Pressure Tests

One part of the original goal of this project was to determine the effectiveness of the Crown Press to predict the performance of BFPs in response to changes in belt tension. To test the effect of belt tension on the Crown Press, the applied pressure was varied. The laboratory results showed that as the pressure increased, the cake solids increased, but with decreasing solids capture efficiency. It was clear from the laboratory results that the driving force in WAS dewatering is the pressure applied to the sludge. Although the cake solids increased as the time under pressure increased also, this effect was not as great as the effect of the applied pressure. Therefore, increasing the belt tension on the BFPs should increase the cake solids. Unfortunately, this is not possible on the BFPs at the Mauldin Road plant. The hydraulic cylinder pressures on all of the presses are within 50 psi of the maximum allowable pressure. Because the pressure cannot be increased, it would be logical to decrease the pressure on the BFPs to determine if the cake solids would likewise decrease. As was the case with an increase in pressure, a decrease in pressure is not possible at the present time either. Once a new belt is put on the BFP and the pressure on the belt is set, the belt will stretch under the applied pressure. If the pressure was decreased, the belt would misalign and separate from the opposite belt due to the slack in the belt. The solids content of the cakes would definitely decrease, but this would be caused by the separation of the belts in the high-pressure

zone, not as a direct result of the lower pressure. Therefore, the only time a lower pressure could potentially be tested is when the belts on the BFP are changed. This is, however, infrequent, with the typical lifespan of a belt being longer than 6 months.

5.3 Cost Analysis

One of the benefits of using a laboratory test to predict the performance of different polymers or different belt materials is the time that is saved by eliminating those polymers or belt materials that are not suited to a particular sludge. In the case of the WAS from the Mauldin Road WWTP, the Crown Press predicted that two of the polymers would perform better than the plant's current polymer, two would perform on a similar level, and one would perform worse than the current polymer. The Crown Press also predicted that none of the different belt materials tested would be useful to the Mauldin Road facility. Had this process been used for an actual polymer trial in which the plant was planning to accept bids for a new polymer, several of the polymers that might have been tried could have been ruled out early in the process. This would have saved both the plant operators and the polymer salesmen considerable time.

One of the disadvantages of both laboratory and plant polymer tests is determining the cost to the plant to use a different polymer for conditioning. After contacting various polymer companies, it was discovered that the retail price quoted for polymers is rarely the price that the company actually quotes in a bid. In most cases, polymer salesmen will bid a price for polymer that is well below the reported retail price. Because WCRSA must use a bidding process to change polymers, determining how cost effective a different polymer would be prior to receiving the bid is almost impossible.

This made it difficult to determine what, if any, cost benefit there would be to WCRSA to use SD 2085 instead of ES 1598. It was clear from the plant tests with SD 2085 that a higher polymer dose would be required to achieve better dewatering. This means that the plant would definitely have to use more SD 2085 per ton of sludge than it currently uses with ES 1598. However, because SD 2085 is an emulsion polymer (lower percent activity) its quoted retail price is less than the retail price of ES 1598. This means that SD 2085 could potentially be cheaper to use than ES 1598, but without knowing the true cost difference between SD 2085 and ES 1598, this cannot be determined.

5.4 Metals Tests

The addition of Mg^{2+} and Ca^{2+} to mixed liquor in order to improve dewaterability was shown to be effective by Higgins and Novak (1996). This study found that Mg^{2+} and Ca^{2+} added to WAS from the Mauldin Road WWTP improved final cake solids by 1.8% solids. These results suggest that the addition of cations to sludge in either the aeration basins or at the BFP facility could improve the dewaterability of the WAS. These cations could be added in several forms, two of them being the chloride and the hydroxide salts. In the laboratory, $MgCl_2$ and $CaCl_2$ were added to the WAS. This could be done at the plant by directly adding the salts to the WAS with the polymer. As stated earlier, this would be an extra operating cost for the facility. Another option is to add the hydroxide salts to the aeration basins. This would provide not only improved dewaterability, but would also provide additional alkalinity for nitrification. In this part of the country the water is typically deficient in alkalinity, which can affect the efficiency of the nitrification process. By adding $Mg(OH)_2$ and $Ca(OH)_2$ to the aeration basins, the

alkalinity of the water would increase and the cations would be available to improve the dewatering characteristics of the mixed liquor. In addition, based on cost figures for the chloride and hydroxide salts from a local chemical company, the hydroxide salts are cheaper. Even with the cheaper hydroxide salts, however, the increase in cake solids would have to be substantial enough to decrease the amount of kiln dust added for stabilization in order to make the addition of the cations cost effective.

5.5 Pressure Washing

The BFP facility at the Mauldin Road plant has a high-pressure hot water washer that it can use to clean half the width of one belt on a BFP. This device is marketed to provide additional removal of solids and polymer from the weave of the belt that the in-line pressure washer cannot remove. The operators do not use the pressure washer all the time for several reasons, the most important being that their experience with the device suggests that it provides only minimal and temporary improvement in belt quality. Based on the claims made by the machine manufacturer and the operator's experience, a small study was conducted to determine if there was any real benefit to using the pressure washer to remove excess solids and polymer. Because these tests did not bear any direct relation to the rest of the project, the procedures and results are presented in Appendix E. The tests showed that on press #2 cake solids from the washed portion of the belt were higher than cake solids from the unwashed portion of the belt. On press #4, however, there was no difference in the cake solids from the washed and unwashed portion of the belt. This could be due to the difference in total usage of the belts on the two presses or to a difference in the in-line pressure washing system on the two presses. Nevertheless, the benefit of the pressure washer appears to be press dependent.

CHAPTER 6

CONCLUSIONS

There were six main objectives in this project, all of which built on the previous work done with the Crown Press. Referring to the objectives in Chapter 1, each individual element was addressed with various laboratory and plant tests. Overall, the objectives of the project were met, and in some instances exceeded. The following are the specific conclusions that were made based on all of the test results.

1. The Crown Press series of single press tests developed by Galla et al. (1996) was capable of replicating the performance of WAS dewatering on BFPs. Cake solids produced by the Crown Press fell within the established operating region for the BFPs at the Mauldin Road wastewater treatment plant.

2. Solids capture efficiency can be calculated for Crown Press tests. This required collection of pressate and belt wash water, which were analyzed for total suspended solids concentration. These values, in addition to the total solids in the press cake, were used to determine the percent of the initial solids that remained in the press cake. Capture efficiencies were found to decrease as applied pressure increased.

3. The Crown Press was effective at evaluating several polymers and differentiating the effect of polymer dose on final cake solids. The results of the various polymer tests on the Crown Press revealed that two of the polymers were more effective conditioners than the plant's current polymer (ES 1598).

4. The Crown Press was a useful tool in choosing two different polymers to be tested on the BFPs at the Mauldin Road WWTP. The Crown Press predicted that the first

polymer chosen, Cytec's Superfloc SD 2085, would achieve higher cake solids than the plant's current polymer. The second polymer, Allied Colloid's Percol 775 FS25, was predicted to perform similarly to the plant's polymer. The plant tests with both of these polymers showed that the Crown Press predictions were accurate.

5. An analysis of the performance of the four BFPs at the Mauldin Road WWTP revealed that there is a statistically significant difference in the cake solids achieved by each of the presses, with the exception of presses #2 and #4. This means that only the cake solids from presses #2 and #4 can be directly compared. In order to compare the cake solids between any other combination of presses, the difference in performance of the presses must be taken into account.

6. The Crown Press more accurately predicted the performance of the two polymers tested on the BFPs than the CST and SRF tests. Although CST, SRF and the Crown Press all indicated that higher polymer doses would be required for Superfloc SD 2085 and Percol 775 FS25 than would be required for ES 1598, only the Crown Press demonstrated that SD 2085 would achieve higher cake solids than either Percol 775 FS25 or ES 1598. In fact, SRF indicated that Percol 775 FS25 had the highest potential for effective dewaterability based on its lowest SRF value, which did not prove true.

7. The Crown Press was also effective in evaluating the influence of specific divalent cations on dewatered cake solids. When high concentrations of both Mg^{2+} and Ca^{2+} were added to unconditioned WAS, the final cake solids increased by an average 1.8% solids.

8. The belt speed indicators on the BFPs at the Mauldin Road WWTP were found to be inaccurate. On all four BFPs the actual belt speed was higher than the indicator belt

speed. Decreasing the belt speed on the BFPs to increase the time under pressure did not increase the cake solids, as was predicted by laboratory results. This could potentially be due to the poor condition of the belts after in-line cleaning or the greater importance of pressure versus time in determining WAS dewaterability on BFPs.

9. The microwave analysis of cake solids used at the BFP facility was found to over estimate cake solids by 1.2% solids. This indicates that the microwave does not completely dry the cake sample in the amount of time used for solids analysis.

10. The improvement in cake solids on the Crown Press achieved with Mg^{2+} and Ca^{2+} enhanced sludge suggests that there may be some potential for using cation adjustment at the plant. This could be done in several locations in the plant including the aeration basins, the DAF tanks, or with the polymer addition using either hydroxide or chloride salts.

CHAPTER 7

RECOMMENDATIONS

There are several areas of this project that would benefit from further study. These recommendations are based on a review of the literature relating to laboratory predictions of sludge dewaterability, the results obtained from the plant testing, and issues raised during the course of this project that could not be addressed.

1. Two additional laboratory tests should be conducted in conjunction with CST and SRF tests. The first is to measure the viscosity of the filtrate from press tests to identify optimum polymer dosage. This test was presented by Christensen et al. (1993) and was found to be an accurate predictor of optimum polymer dosage. The second is the $Spin_{45K}$ test presented by Barber et al. (1997) which is used by staff at the Eastman Chemical Company's WWTP to determine changes in the dewatering characteristics of activated sludge.

2. During laboratory polymer testing, ES 1598 was not extensively tested at various polymer doses. The effect of polymer dose on final cake solids with ES 1598 should be investigated with the Crown Press. If these tests indicate an improvement in cake solids with increasing dose, tests should be conducted on the BFPs with increased ES 1598 doses.

3. The plant polymer tests using Superfloc SD 2085 should be repeated when all four presses are operating properly. These tests should be conducted for multiple days using various polymer doses. The results from these tests would be used to verify the results from the plant testing conducted in this project.

4. The belt speed indicators on the BFPs should be calibrated. This would provide a more accurate measure of the times under pressure used by the plant. In addition, the pressure gauges for the hydraulic cylinders should be verified to ensure that the appropriate pressures are used in calculating the operating region of the BFPs.

5. The plant survey should be continued and more plants that are using biological phosphorus removal included.

6. Additional plants that are dewatering WAS with BFPs should be included in both laboratory and plant tests. This will provide information regarding the performance of Mauldin Road's WAS as compared to other WWTPs.

7. More final cake samples should be tested for solids content using both the microwave and oven techniques to calibrate the results.

8. The adjustment of the cation concentration in the WAS should be evaluated further. These tests should include using the hydroxide salts with ES 1598 and SD 2085 to determine if these salts provide the same improvement in dewaterability as was found with the chloride salts. The cation concentration of the mixed liquor should be measured to determine if the monovalent/divalent and Ca^{2+}/Mg^{2+} ratios are the same as those determined with the secondary effluent data.

APPENDICES

Appendix A

Correlation between Indicator and Actual Belt Speeds

The following tables show the data for the belt speed verification tests. The distance used to determine the actual belt speed was 78.5 in. Each set of data was analyzed using a linear regression. The equation relating the actual belt speed to the indicator belt speed for each press is listed at the bottom of each table.

Table A.1 Press #1.

Indicator Speed (ft/min)	Time (s)	Actual Speed (ft/min)	Difference
12.3	28.49	13.78	1.48
13.8	25.46	15.42	1.62
14.6	23.78	16.51	1.91
16.6	21.10	18.60	2.00
17.3	20.36	19.28	1.98
19.3	18.21	21.55	2.25
20.3	17.12	22.93	2.63
22.0	15.95	24.61	2.61
24.2	14.68	26.74	2.54
25.1	14.22	27.60	2.50

$$Belt\ speed_{actual} = 1.09(Belt\ speed_{indicator}) + 0.52$$

$R^2 = 0.999$

Table A.2 Press #2.

Indicator Speed (ft/min)	Time (s)	Actual Speed (ft/min)	Difference
12.2	28.47	13.79	1.59
14.8	23.73	16.54	1.74
17.0	20.21	19.42	2.42
18.6	18.66	21.03	2.43
20.0	17.57	22.34	2.34
23.1	15.20	25.82	2.72

$$Belt\ speed_{actual} = 1.11(Belt\ speed_{indicator}) + 0.33$$

$R^2 = 0.998$

Table A.3 Press #3.

Indicator Speed (ft/min)	Time (s)	Actual Speed (ft/min)	Difference
30.0	11.90	32.98	2.98
26.0	13.50	29.07	3.07
22.5	15.40	25.49	2.99
20.0	17.80	22.05	2.05
16.0	21.80	18.00	2.00
13.0	26.67	14.72	1.72
10.2	33.98	11.55	1.35

$$Belt\ speed_{actual} = 1.09(Belt\ speed_{indicator}) + 0.50$$

$R^2 = 0.999$

Table A.4 Press #4.

Indicator Speed (ft/min)	Time (s)	Actual Speed (ft/min)	Difference
21.6	16.31	24.06	2.46
19.0	18.35	21.39	2.39
17.0	20.84	18.83	1.83
15.0	23.25	16.88	1.88
12.9	27.09	14.49	1.59

$$Belt\ speed_{actual} = 1.11(Belt\ speed_{indicator}) + 0.24$$

$R^2 = 0.999$

Appendix B

Belt Tension Algorithm

The following algorithm was used to convert hydraulic cylinder pressures to belt tensions. This information was provided by personnel at Eimco.

The pressure of the hydraulic cylinder for the long belt is used to calculate belt tension. For the Mauldin Road BFPs, the pressure on this hydraulic cylinder is typically 450 psi. The following steps will use this pressure as an example calculation.

Step 1: Calculate the area of the cylinder on the pressure side of the piston.

$$Area = \frac{\pi\left[(bore\,diameter)^2 - (piston\,shaft\,diameter)^2\right]}{4}$$

$$Area = \frac{\left[(4in)^2 - (1.5in)^2\right]}{4} = 10.8\,in^2$$

Step 2: Calculate the force due to hydraulic pressure on the hydraulic cylinder.

$$Force = hydraulic\ pressure \times piston\ area$$

$$Force = 450\,psi \times 10.8\,in^2$$

$$Force = 4860\,lbs$$

Step 3: Calculate the force on the roller due to the hydraulic cylinder.

$$Force_{roller} \times Pivet\,arm_{roller} = Force_{cylinder} \times Pivet\,arm_{cylinder}$$

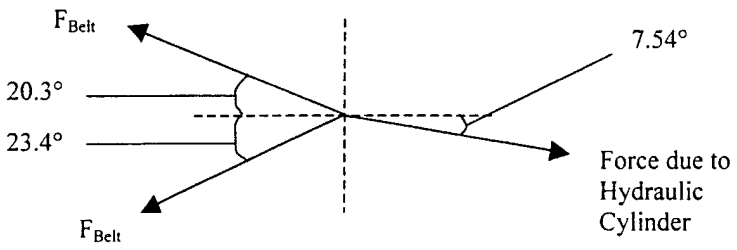
$$Force_{roller} = \frac{4860lbs \times 21.86in}{33.93in}$$

$$Force_{roller} = 3131\,lbs$$

Step 4: Since there are two tension cylinders, the force on the roller must be doubled.

$$Total\ Force_{roller} = 2 \times 3131\,lbs = 6262\,lbs$$

Step 5: Calculate the force on the belt due to the force of the roller. This must include the angles of the belt and of the cylinder in the force balance.



$$\sum Forces = 0$$

$$0 = F_{Belt} \cos 20.3^{\circ} + F_{Belt} \cos 23.4^{\circ} - 6262 \cos 7.54^{\circ}$$

$$Force_{Belt} = 3345\ lbs$$

Step 6: Calculate the force on the belt in terms of the belt width. The belts on the Mauldin Road Eimco BFPs are 2.2 meters (86.6 in.) wide.

$$Belt\ tension\ (lbs / lineal\ in) = Force_{Belt} \times belt\ width$$

$$\boxed{Belt\ tension = 3345 lbs \div 86.6 in = 38.6 lbs / in}$$

Appendix C

Experimental Data

The following tables provide all of the data used to produce the graphical figures in this report.

Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation
10	2.41	1.38	11.70	0.71
20		1.68	12.01	0.59
40		1.98	13.34	0.86
60		2.16	14.18	0.67
10	3.66	1.56	12.41	0.40
20		1.86	13.29	0.47
40		2.17	14.57	0.85
60		2.34	15.36	0.64
10	4.90	1.69	13.82	0.73
20		1.99	14.50	0.82
40		2.29	15.41	0.59
60		2.47	15.90	0.50

Figure 4.1 data (PCS from 5/6/97).

Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation
20	1.16	1.37	11.69	0.57
30		1.54	12.73	0.67
40		1.67	11.93	0.36
60		1.84	12.27	0.47
80		1.97	13.34	0.91
20	2.41	1.68	13.17	0.20
40		1.98	13.92	0.31
60		2.16	13.88	0.49
80		2.29	14.2	0.23
20	3.66	1.86	13.04	0.27
40		2.17	14.2	0.10
60		2.34	15.07	0.20

Figure 4.2 data (PCS from 6/5/97).

Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation
20	1.16	1.37	11.71	0.29
40		1.67	12.91	0.14
60		1.84	13.50	0.56
80		1.97	13.49	0.21
100		2.06	13.69	0.06
20	1.79	1.55	12.78	0.07
40		1.85	13.94	0.09
60		2.03	13.89	0.56
80		2.16	13.68	0.16
100		2.25	14.48	0.12
20	2.41	1.68	12.99	0.31
40		1.98	14.14	0.14
60		2.16	14.03	0.10
80		2.29	14.51	0.22
100		2.38	14.83	0.32
20	3.66	1.86	13.82	0.51
40		2.17	14.77	0.47
60		2.34	15.27	0.16
80		2.47	14.91	0.46
100		2.56	15.99	0.05

Figure 4.3 data (PCS from 7/11/97).

Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	PCS Final Cake Solids (%)	LCS Final Cake Solids (%)
20	1.16	1.37	12.18	12.60
40		1.67	13.08	12.86
60		1.84	13.81	12.95
80		1.97	13.78	13.50
100		2.06	14.68	N/A
20	1.79	1.55	13.25	12.00
40		1.85	13.61	12.73
60		2.03	14.66	13.36
80		2.16	15.49	13.79
20	2.41	1.68	13.19	13.07
40		1.98	14.49	13.25
60		2.16	15.03	14.21
80		2.29	14.37	13.74
20	3.66	1.86	13.99	N/A
40		2.17	15.33	N/A
60		2.34	15.30	N/A
80		2.47	16.18	N/A

Figure 4.4 (PCS and LCS from 6/24/97).

Polymer Dosage (lb/ton)	SRF, r (cm/g)	CST (s)
4.54	4.07E+12	223.65
6.05	6.30E+11	40.68
7.57	1.05E+11	15.05
9.08	3.53E+10	13.05
10.6	N/A	15.40
12.11	N/A	32.08
13.62	5.09E+10	31.60
15.14	1.26E+12	48.57

Figure 4.5 data (ES 1598).

Polymer Dosage (lb/ton)	SRF, r (cm/g)	CST (s)
7.40	1.50E+12	103.43
8.88	4.99E+11	36.83
10.36	1.23E+11	14.87
11.84	5.38E+10	13.90
13.32	6.06E+10	12.65
14.80	4.19E+11	16.23
16.28	2.40E+11	22.47

Figure 4.6 data (Superfloc SD 2081).

Volume Polymer, mL	Polymer Dose, lb/ton	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation
12	9.26	15	1.16	1.24	10.76	0.43
		30		1.54	12.14	0.44
		45		1.72	11.83	0.43
		60		1.84	12.58	0.79
		15	2.41	1.56	12.25	0.31
		30		1.86	12.70	0.47
		45		2.04	13.32	0.04
16	12.34	15	1.16	1.24	12.34	0.49
		30		1.54	12.47	0.08
		45		1.72	12.57	0.06
		60		1.84	13.23	0.58
		15	2.41	1.56	12.41	0.45
		30		1.86	13.37	0.54
		45		2.04	13.69	0.44
		60		2.16	13.79	0.38
		15	3.66	1.74	13.65	0.20
		30		2.04	14.83	0.42
		45		2.22	15.37	0.39
		60		2.34	15.49	0.42
20	15.43	15	1.16	1.24	12.64	0.54
		30		1.54	13.19	0.50
		45		1.72	14.20	0.32
		60		1.84	13.97	0.46
		15	2.41	1.56	13.47	0.37
		30		1.86	14.23	0.48
		45		2.04	14.53	0.40
		60		2.16	14.93	0.50
		15	3.66	1.74	13.54	0.57
		30		2.04	15.09	0.52
		45		2.22	15.49	0.59
		60		2.34	15.90	0.47
30	22.68	15	1.16	1.24	13.02	0.17
		30		1.54	13.21	0.03
		45		1.72	13.44	0.53
		60		1.84	14.40	0.33
		15	2.41	1.56	13.54	0.35
		30		1.86	14.70	0.44
		45		2.04	15.33	0.22
		60		2.16	15.63	0.62
		15	3.66	1.74	14.45	0.34
		30		2.04	14.80	0.16
		45		2.22	15.88	0.27
		60		2.34	15.77	0.27

Figure 4.7 data (Superfloc SD 2081).

Polymer Dosage (lb/ton)	SRF, r (cm/g)	CST (s)
8.77	6.30E+12	287.93
10.23	1.48E+12	66.10
11.69	5.91E+11	22.00
13.16	9.54E+10	15.23
14.62	2.27E+10	14.87
16.08	2.67E+10	13.00
17.54	2.48E+10	11.73
19.00	3.13E+11	16.37
20.46	1.50E+11	20.00

Figure 4.8 data (Superfloc SD 2085).

Volume Polymer, mL	Polymer Dose, lb/ton	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation	Capture Efficiency (%)
18	13.2	15	1.16	1.24	12.27	0.30	99.38
		30		1.54	12.48	0.19	93.08
		45		1.72	13.47	0.23	97.15
		60		1.84	13.35	0.44	93.34
		15	2.41	1.56	11.77	0.06	98.71
		30		1.86	12.53	0.22	96.26
		45		2.04	13.52	0.16	95.17
		60		2.16	13.71	0.29	90.97
		15	3.66	1.74	12.50	0.20	86.73
		30		2.04	12.94	0.25	91.88
		45		2.22	14.43	0.31	87.79
		60		2.34	14.67	0.21	87.91
20	15.2	15	1.16	1.24	11.77	0.14	94.67
		30		1.54	12.15	0.24	94.59
		45		1.72	12.79	0.20	96.65
		60		1.84	13.03	0.62	95.84
		15	2.41	1.56	12.92	0.45	95.77
		30		1.86	14.26	0.23	94.63
		45		2.04	14.61	0.41	95.18
		60		2.16	14.82	0.35	95.35
		15	3.66	1.74	14.45	0.75	92.43
		30		2.04	14.92	0.45	93.44
		45		2.22	15.37	0.60	89.75
		60		2.34	15.80	0.45	90.74
		15	4.90	1.87	13.81	0.26	87.26
		30		2.17	15.20	0.57	77.71
		45		2.34	14.81	0.48	85.42
		60		2.47	15.37	0.26	87.35

Figures 4.9-4.14 data (Superfloc SD 2085)

Volume Polymer, mL	Polymer Dose, lb/ton	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation	Capture Efficiency (%)
24	18.2	15	1.16	1.24	13.22	0.37	99.49
		30		1.54	14.29	0.28	99.49
		45		1.72	14.35	0.31	99.63
		60		1.84	14.83	0.70	99.67
		15	2.41	1.56	13.69	0.57	99.09
		30		1.86	15.16	0.20	98.74
		45		2.04	15.81	0.38	98.31
		60		2.16	15.97	0.47	98.24
		15	3.66	1.74	14.45	0.67	96.24
		30		2.04	14.76	0.77	96.51
		45		2.22	15.74	0.79	92.86
		60		2.34	15.80	0.49	94.40
		15	4.90	1.87	15.10	0.09	95.58
		30		2.17	16.05	0.48	93.24
		45		2.34	16.42	0.65	94.64
		60		2.47	17.04	0.48	94.14
28	21.6	15	1.16	1.24	14.42	0.52	99.45
		30		1.54	14.20	0.58	99.70
		45		1.72	14.69	0.61	99.69
		60		1.84	15.27	0.40	99.77
		15	2.41	1.56	14.77	0.84	99.45
		30		1.86	15.44	0.38	99.43
		45		2.04	16.25	0.62	98.71
		60		2.16	16.13	0.52	98.59
		15	3.66	1.74	14.46	0.40	97.51
		30		2.04	14.99	0.51	99.01
		45		2.22	16.05	0.65	97.13
		60		2.34	16.74	0.21	97.23
		15	4.90	1.87	14.97	0.41	97.53
		30		2.17	16.91	0.49	93.41
		45		2.34	17.44	0.33	90.98
		60		2.47	17.46	0.36	93.78

Figures 4.9-4.14 data, continued (Superfloc SD 2085)

Polymer Dosage (lb/ton)	SRF, r (cm/g)	CST (s)
6.28	2.21E+12	202.90
8.37	5.64E+11	88.83
10.46	8.75E+10	14.90
12.55	4.98E+10	14.13
14.64	3.85E+10	14.65
16.74	5.35E+10	50.43
18.83	2.86E+10	43.12

Figure 4.15 data (Superfloc C-496).

Polymer Dosage (lb/ton)	SRF, r (cm/g)	CST (s)
6.77	1.14E+13	202.78
9.02	8.80E+12	81.50
11.28	2.26E+11	20.38
13.54	3.10E+10	13.37
15.79	2.58E+10	13.80
18.05	1.53E+11	30.27
20.30	8.07E+10	41.17
22.56	1.42E+11	45.08

Figure 4.20 data (Percol 778 FS25).

	Polymer Dosage (lb/ton)	Ave CST (s)	CST Std Dev	SRF, r (cm/g)
No Metals	6.10	55.9	8.72	5.31E+11
	10.16	14.1	2.81	7.04E+09
	14.23	37.2	2.37	1.59E+11
Metals	6.10	59.1	3.91	2.99E+11
	10.16	12.9	2.33	2.59E+10
	14.23	23.3	1.36	4.72E+10

Figure 4.23 data (ES 1598).

Volume Polymer, mL	Polymer Dose, lb/ton	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation
10	10.9	15	1.16	1.24	10.32	0.16
		30		1.54	10.90	0.08
		45		1.72	11.38	0.24
		60		1.84	11.08	0.14
		15	2.41	1.56	10.63	0.36
		30		1.86	11.78	0.19
		45		2.04	12.30	0.48
		60		2.16	12.01	0.16
		15	3.66	1.74	11.32	0.95
		30		2.04	11.76	1.03
		45		2.22	12.79	0.92
		60		2.34	13.07	0.69
14	15.3	15	1.16	1.24	10.56	0.37
		30		1.54	11.00	0.44
		45		1.72	11.28	0.28
		60		1.84	11.43	0.31
		15	2.41	1.56	10.85	0.28
		30		1.86	11.15	0.21
		45		2.04	11.89	0.27
		60		2.16	12.53	0.60
		15	3.66	1.74	11.67	0.44
		30		2.04	12.06	0.25
		45		2.22	13.09	0.31
		60		2.34	13.47	0.51
18	19.61	15	1.16	1.24	10.32	0.23
		30		1.54	11.14	0.22
		45		1.72	11.32	0.14
		60		1.84	11.73	0.47
		15	2.41	1.56	11.45	0.27
		30		1.86	12.26	0.11
		45		2.04	12.27	0.34
		60		2.16	12.25	0.38
		15	3.66	1.74	11.66	0.23
		30		2.04	11.79	0.28
		45		2.22	12.31	0.24
		60		2.34	12.71	0.39

Figure 4.16 data (Superfloc C-496)

Polymer Dosage (lb/ton)	SRF, r (cm/g)	CST (s)
8.92	1.03E+13	506.60
11.16	4.47E+12	132.73
13.39	1.32E+12	41.43
15.62	1.37E+10	14.53
17.85	1.56E+10	12.60
20.08	3.03E+10	52.38
22.31	9.01E+11	67.10

Figure 4.17 data (Percol 775 FS25).

Volume Polymer, mL	Polymer Dose, lb/ton	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation	Capture Efficiency (%)
12	12.6	15	1.16	1.24	11.17	0.09	97.05
		30		1.54	12.05	0.42	93.89
		45		1.72	12.32	0.28	95.35
		60		1.84	13.22	0.60	94.71
		15	2.41	1.56	12.42	0.16	90.03
		30		1.86	13.03	0.29	90.95
		45		2.04	13.85	0.44	88.94
		60		2.16	13.69	0.37	93.50
		15	3.66	1.74	13.50	0.51	82.00
		30		2.04	14.08	0.31	83.27
		45		2.22	14.40	0.36	85.51
		60		2.34	14.56	0.29	83.46
14	14.7	15	1.16	1.24	11.74	0.26	97.88
		30		1.54	12.21	0.38	96.90
		45		1.72	12.35	0.37	97.46
		60		1.84	12.74	0.34	97.79
		15	2.41	1.56	12.13	0.22	91.70
		30		1.86	12.66	0.42	93.37
		45		2.04	13.30	0.07	91.72
		60		2.16	14.00	0.47	91.69
		15	3.66	1.74	13.06	0.18	88.65
		30		2.04	13.56	0.31	89.99
		45		2.22	13.68	0.37	90.25
		60		2.34	14.43	0.43	92.56
		15	4.90	1.87	14.01	0.14	82.79
		30		2.17	14.49	0.49	85.41
		45		2.34	14.91	0.37	83.76
		60		2.47	15.24	0.45	80.75

Figures 4.18-4.19 data (Percol 775 FS25)

Volume Polymer, mL	Polymer Dose, lb/ton	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation	Capture Efficiency (%)
16	17.1	15	1.16	1.24	12.01	0.26	97.14
		30		1.54	13.06	0.37	94.62
		45		1.72	13.44	0.16	94.45
		60		1.84	12.97	0.22	96.00
		15	2.41	1.56	13.17	0.32	86.27
		30		1.86	13.87	0.28	90.28
		45		2.04	14.68	0.30	86.51
		45		2.04	14.479	0.21	90.76
		60		2.16	14.20	0.24	92.83
		60		2.16	14.422	0.37	90.22
		15	3.66	1.74	13.77	0.20	89.45
		30		2.04	14.03	0.37	88.54
		45		2.22	14.95	0.39	78.41
		60		2.34	15.19	0.34	83.54
		15	4.90	1.87	14.42	0.32	75.07
		30		2.17	15.10	0.30	72.64
18	19.2	15	1.16	1.24	12.01	0.43	96.87
		30		1.54	12.56	0.16	96.13
		45		1.72	12.93	0.37	97.86
		60		1.84	13.22	0.47	95.65
		15	2.41	1.56	12.78	0.20	91.33
		30		1.86	13.33	0.46	89.77
		45		2.04	13.68	0.50	89.76
		60		2.16	14.16	0.49	91.32
		15	3.66	1.74	13.95	0.45	76.74
		30		2.04	13.98	0.21	81.26
		45		2.22	15.17	0.33	80.02
		60		2.34	15.51	0.48	82.31
		15	4.90	1.87	14.07	0.24	76.05
		30		2.17	15.10	0.24	73.31

Figures 4.18-4.19 data, continued (Percol 775 FS25)

Polymer Dose, lb/ton	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation
10.0	15	1.16	1.24	12.44	0.16
	30		1.54	12.99	0.27
	45		1.72	13.56	0.22
	60		1.84	13.90	0.25
	15	2.41	1.56	13.39	0.06
	30		1.86	13.18	0.46
	45		2.04	15.12	0.06
	60		2.16	15.09	0.16
	15	3.66	1.74	14.66	0.36
	30		2.04	14.36	0.49
	45		2.22	16.09	0.45
	60		2.34	15.93	0.18
12.0	15	1.16	1.24	12.74	0.51
	30		1.54	14.01	0.23
	45		1.72	14.82	0.37
	60		1.84	15.22	0.27
	15	2.41	1.56	14.13	0.48
	30		1.86	14.85	0.21
	45		2.04	15.23	0.20
	60		2.16	15.92	0.21
	15	3.66	1.74	13.93	0.16
	30		2.04	14.47	0.35
	45		2.22	14.96	0.27
	60		2.34	15.18	0.26
	15	4.90	1.87	14.67	0.24
	30		2.17	15.47	0.31
	45		2.34	16.12	0.28
	60		2.47	16.50	0.35
16.0	15	1.16	1.24	12.71	0.24
	30		1.54	13.94	0.40
	45		1.72	14.84	0.38
	60		1.84	14.98	0.38
	15	2.41	1.56	13.56	0.24
	30		1.86	14.39	0.14
	45		2.04	14.98	0.39
	60		2.16	14.28	0.52
	15	3.66	1.74	14.15	0.34
	30		2.04	14.59	0.38
	45		2.22	15.62	0.35
	60		2.34	15.78	0.40
	15	4.90	1.87	14.57	0.35
	30		2.17	15.37	0.29
19.0	15	1.16	1.24	13.16	0.33
	30		1.54	13.65	0.40
	45		1.72	14.37	0.30
	60		1.84	14.91	0.17
	15	2.41	1.56	14.00	0.53
	30		1.86	15.00	0.58
	45		2.04	15.70	0.32
	60		2.16	15.42	0.33
	15	3.66	1.74	14.72	0.36
	30		2.04	15.80	0.32
	45		2.22	16.29	0.41
	60		2.34	15.97	0.55

Figure 4.21 data (Percol 778 FS25)

Belt Type	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation
Mauldin Rd Belt	15	1.16	1.24	12.74	0.25
	30		1.54	13.60	0.55
	45		1.72	14.11	0.38
	60		1.84	14.26	0.26
	15	2.41	1.56	13.74	0.32
	30		1.86	14.58	0.22
	45		2.04	15.30	0.39
	60		2.16	15.39	0.37
	15	3.66	1.74	14.20	0.42
	30		2.04	14.87	0.31
	45		2.22	15.11	0.27
	60		2.34	15.46	0.22
Filter Belts 21/8F	15	1.16	1.24	11.52	0.53
	30		1.54	12.39	0.57
	45		1.72	12.93	0.34
	60		1.84	13.17	0.47
	15	2.41	1.56	12.21	0.39
	30		1.86	12.53	0.54
	45		2.04	13.09	0.61
	60		2.16	13.38	0.45
	15	3.66	1.74	12.74	0.56
	30		2.04	12.96	0.60
	45		2.22	13.30	0.41
	60		2.34	13.45	0.53

Belt Type	Time Under Pressure (s)	Pressure (psi)	Log (Pressure* Time)	Final Cake Solids (%)	Standard Deviation
Filter Belts 19/6 HDF	15	1.16	1.24	11.49	0.44
	30		1.54	12.23	0.05
	45		1.72	12.59	0.20
	60		1.84	13.05	0.38
	15	2.41	1.56	12.76	0.31
	30		1.86	13.25	0.48
	45		2.04	13.73	0.48
	60		2.16	13.96	0.35
	15	3.66	1.74	12.80	0.09
	30		2.04	13.26	0.24
	45		2.22	14.08	0.24
	60		2.34	14.38	0.34
Industrial Fabrics 6461	15	1.16	1.24	12.44	0.21
	30		1.54	13.13	0.75
	45		1.72	13.62	0.53
	60		1.84	14.21	0.20
	15	2.41	1.56	13.36	0.13
	30		1.86	13.84	0.48
	45		2.04	14.39	0.70
	60		2.16	14.57	0.40
	15	3.66	1.74	13.59	0.39
	30		2.04	14.21	0.39
	45		2.22	14.38	0.58
	60		2.34	14.68	0.42
Industrial Fabrics 6912	15	1.16	1.24	12.27	0.65
	30		1.54	12.65	0.78
	45		1.72	12.90	0.47
	60		1.84	13.14	0.54
	15	2.41	1.56	12.52	0.37
	30		1.86	13.07	0.19
	45		2.04	13.63	0.84
	60		2.16	13.93	0.18

Figure 4.22 data (Belt Testing)

				No Metals Added		Mg^{2+} & Ca^{2+} Added	
Polymer Dose, lb/ton	Time Under Pressure (s)	Pressure (psi)	Log (Pressure*Time)	Final Cake Solids (%)	Standard Deviation	Final Cake Solids (%)	Standard Deviation
8.82	30	1.16	1.54	12.18	0.47	13.97	0.46
	60		1.84	13.08	0.47	14.50	0.60
	30	2.41	1.86	13.51	0.29	14.92	0.24
	60		2.16	14.05	0.39	16.17	0.40
	30	3.66	2.04	14.12	0.59	16.00	0.32
	60		2.34	14.85	0.60	17.14	0.39
11.02	30	1.16	1.54	12.69	0.54	14.17	0.18
	60		1.84	13.12	0.54	15.22	0.69
	30	2.41	1.86	13.98	0.36	15.44	0.48
	60		2.16	14.06	0.29	16.19	0.74
	30	3.66	2.04	14.38	0.45	16.32	0.39
	60		2.34	15.38	0.50	16.51	0.80

Figure 4.24 data (ES 1598)

Polymer	Time Under Pressure (s)	Pressure (psi)	Log (Pressure*Time)	Final Cake Solids (%)	Standard Deviation
Percol 775 FS25, 3/30/98	30	1.16	1.54	11.20	0.54
	60		1.84	11.97	0.36
	30	2.41	1.86	12.19	0.44
	60		2.16	13.17	0.30
	30	3.66	2.04	13.04	0.32
	60		2.34	14.14	0.16
SD 2085, 4/1/98	30	1.16	1.54	11.95	0.25
	60		1.84	13.24	0.20
	30	2.41	1.86	13.68	0.25
	60		2.16	14.11	0.39
	30	3.66	2.04	14.13	0.52
	60		2.34	15.34	0.53
SD 2085, 4/3/98	30	1.16	1.54	13.19	0.47
	60		1.84	14.13	0.21
	30	2.41	1.86	14.43	0.46
	60		2.16	15.60	0.27
	30	3.66	2.04	14.90	0.68
	60		2.34	15.73	0.92

Figure 4.26 data (PCS)

Appendix D

Absorbance and Suspended Solids Correlation

In order to decrease the amount of time required to determine the total suspended solids concentration of the filtrate samples collected during plant polymer testing, multiple samples were measured for both absorbance and suspended solids. An aliquot of the filtrate sample was added to a test tube. The sample was shaken vigorously, and the absorbance of the sample was measured on a Spec 20 at 620 nm. After inserting the test tube, the absorbance value was recorded after 10 seconds and then every 5 seconds for an additional 20 seconds. After testing approximately 10 samples, a blank sample was inserted into the Spec 20 to verify the calibration of the machine. This process was then repeated for the same 10 samples. The 10 absorbance measurements for each sample were averaged. Table D.1 shows the absorbance and suspended solids concentrations for the samples used to determine the correlation equation. Figure D.1 shows the plot of total suspended solids versus absorbance with a linear regression fit. The R^2 value for the regression was 0.870, indicating a high correlation between absorbance and total suspended solids.

Table D.1 TSS and absorbance data for correlation.

Sample Date	Sample #	TSS, mg/L	Ave Absorbance
3/23/98	#1-11	97	0.056
3/23/98	#1-12	125	0.062
3/23/98	#3-2	255	0.151
3/23/98	#3-5	438	0.235
3/23/98	#3-8	227	0.124
3/23/98	#4-8	33	0.059
3/24/98	#1-7	40	0.054
3/24/98	#1-10	85	0.068
3/24/98	#3-6	85	0.105
3/24/98	#3-8	101	0.081
3/24/98	#4-2	12	0.046
3/24/98	#4-8	13	0.055
3/25/09	#1-5	28	0.063
3/25/98	#1-6	24	0.052
3/25/98	#3-1	166	0.097
3/25/98	#3-2	191	0.149
3/25/98	#3-3	268	0.146
3/25/98	#3-4	227	0.157
3/25/98	#3-5	318	0.212
3/25/98	#3-6	124	0.097
3/25/98	#3-7	295	0.184
3/25/98	#4-3	111	0.122
3/30/98	#2-3	35	0.075
3/30/98	#2-9	40	0.057
3/30/98	#3-3	80	0.073
3/30/98	#3-8	18	0.048
4/1/98	#2-2	5	0.048
4/1/98	#2-4	58	0.088
4/1/98	#2-5	34	0.047
4/1/98	#2-9	15	0.056
4/1/98	#3-6	32	0.090
4/1/98	#3-10	13	0.087
4/2/98	#2-4	16	0.048
4/2/98	#2-5	12	0.056
4/2/98	#3-2	74	0.077
4/2/98	#3-5	80	0.051
4/2/98	#4-1	161	0.136
4/2/98	#4-2	112	0.109
4/3/98	#3-3	62	0.062
4/3/98	#3-7	61	0.057

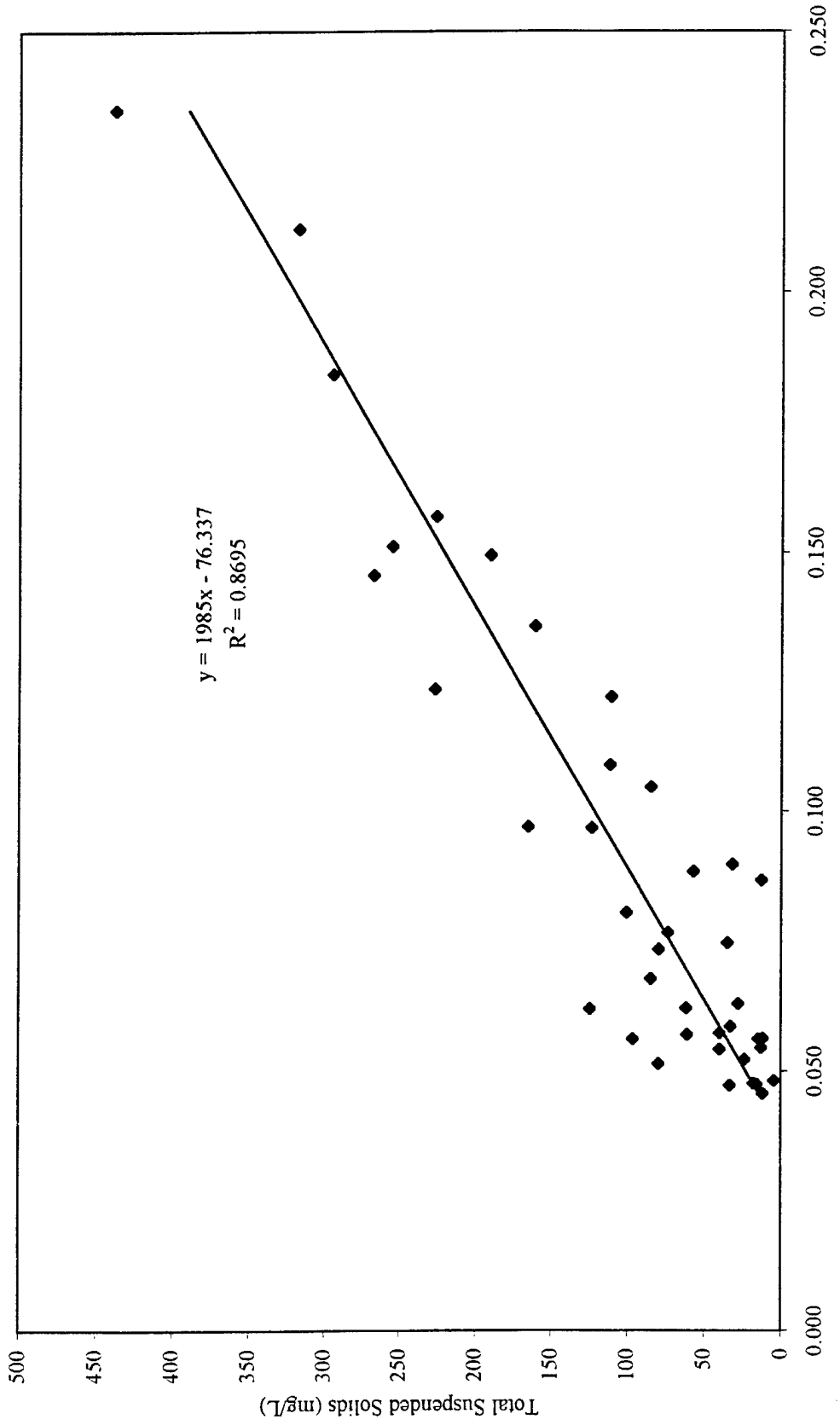


Figure D.1 Absorbance and TSS correlation for filtrate samples.

Appendix E

Belt Wash Tests

One of the potential causes of poor dewatering on a BFP is the quality of the belts. During operation, the belts are continuously cleaned after the cake is removed from the belts with a pressure washer built into the belt press machinery. However, this process normally does not remove all of the solids or polymer that is trapped in the weave of the belts. Figure E.1 is a photograph taken of the top belt of Press #4 at the Mauldin Road facility after it had been cleaned with the built-in pressure washer system. This photo shows that there is a considerable amount of solids on the belt that will impair gravity drainage and possibly dewatering in the high-pressure zone.

The belt press facility has a high-pressure hot water machine that can be used to clean one of the two belts used on the BFP. The flowrate capacity of the machine is such that only one-half the width of the belt can be cleaned at a time. The belt press operators have used the pressure washer when drainage on the belt becomes severely impaired due to excessive build-up of polymer in the weave of the belt. According to the operators, there was little to no improvement in final cake solids when the pressure washer was used. The operators did express that the gravity drainage of the sludge improved during and shortly after pressure washing the belt, but the improvement in gravity drainage did not affect the final cake solids.

To evaluate use of the pressure washer, the top belt of presses #2 and #4 were cleaned during operation on 2 different days. Because the pressure washer can only clean one-half the width of the belt, samples from washed and unwashed portions of the belt could be compared from the same BFP. Cake samples were taken from the end of the gravity drainage zone and from the end of the high-pressure zone throughout the day. The results of these tests are shown in Table E.1.

On press #2, cake solids removed from the washed portion of the belt were an average of 1.6% solids higher than the cake solids removed from the unwashed portion of the belt. On press #4, the dewatered cakes removed from the washed section of the belt had an average of 0.16% solids higher final cake concentration than cakes removed from the unwashed portion of the belt, however based on the number of samples taken, this difference is relatively insignificant.

Table E.1 High-pressure hot water cleaning of Presses #2 and #4.

Sample #	% Cake Solids from Washed portion of belt	% Cake Solids from Unwashed portion of belt
Press 2-1	12.88	11.93
2-2	14.63	12.76
2-3	14.54	13.04
2-4	14.84	12.76
Average	14.22	12.62
Press 4-1	14.09	13.64
4-2	13.56	14.55
4-3	14.70	13.68
Average	14.12	13.96

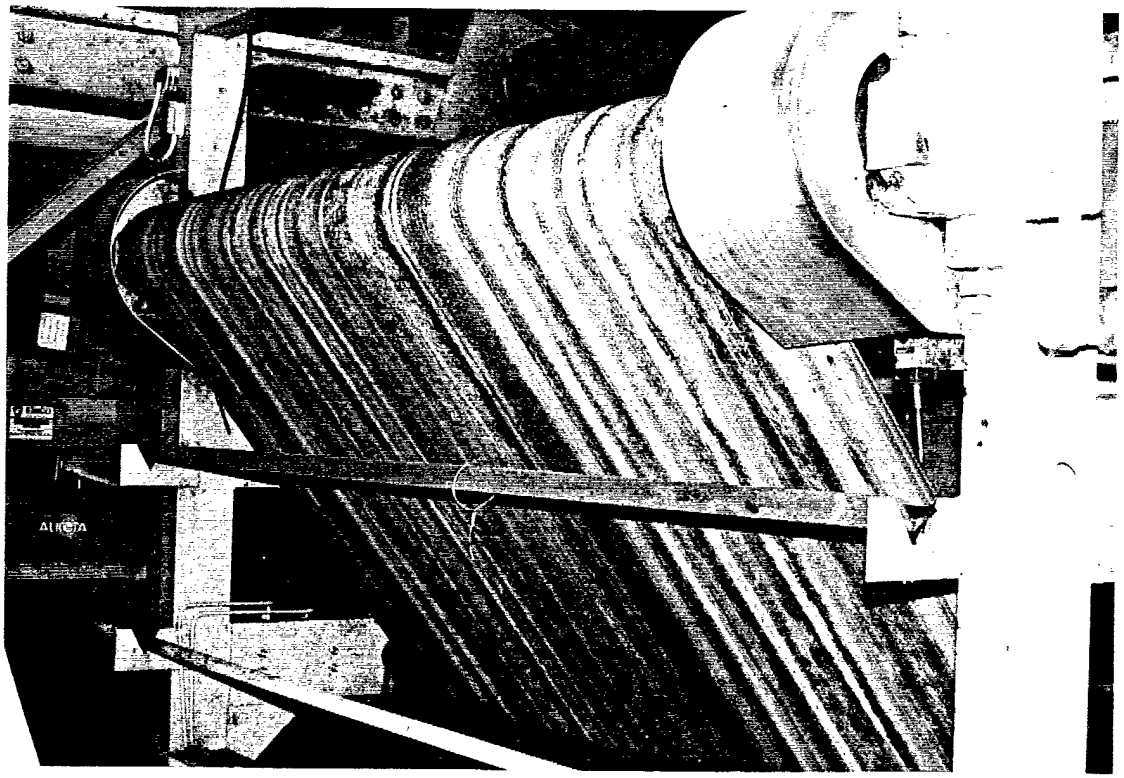


Figure E.1 The top belt on Press #4 after in-line cleaning.

REFERENCES

Abu-Orf, M.M. and S.K. Dentel. (1997). "Polymer dose assessment using the streaming current detector." *Water Environment Research*, 69:6:1075-1085.

Andreasen, I. and B. Nielsen. (1993). "A Comparative Study of Full-Scale Sludge Dewatering Equipment." *Water Science and Technology*, 28:1:37-45.

ASCE Task Committee on Belt Filter Presses. (October 1988). "Belt Filter Press Dewatering of Wastewater Sludge." *J. Environmental Engineering Division, ASCE*, 114:5:991-1006.

Barber, J.B, C.M. Bullard, and M.A. Charles. (1997). "Centrifuge Test Predicts Solids Dewaterability." *Industrial Wastewater*, ##:##:31-36.

Baskerville, R.C., A. M. Bruce, and M. C., Day. (September/October 1978). "Laboratory Techniques for Predicting and Evaluating the Performance of a Filterbelt Press." *Filtration and Separation*, 15:445-454.

Baskerville, R.C. and R. S. Gale. (1968). "A Simple Automatic Instrument for Determining the Filterability of Sewage Sludges." *Water Pollution Control*, 67:233-241.

Bullard, C.M. and J. Barber. (1996). "A Factor in Belt Filter Press Performance." *Water Environment and Technology*, 8:12:67-70.

Christensen, G.L. and R. I. Dick. (June 1985). "Specific Resistance Measurements: Nonparabolic Data." *Journal of Environmental Engineering*, 111:3:243-257.

Christensen, G.L. and R. I. Dick. (June 1985). "Specific Resistance Measurements: Methods and Procedures." *Journal of Environmental Engineering*, 111:3:258-271.

Christensen, J.R., P.B. Sorensen, G.L. Christensen, and J.A. Hansen. (January/February 1993). "Mechanisms for Overdosing in Sludge Conditioning." *Journal of Environmental Engineering*, 119:1:159-171.

Coackley, P. and B.R.S. Jones. (August 1956). "Vacuum Sludge Filtration: Interpretation of results by the Concept of Specific Resistance." *Sewage and Industrial Wastes*, 28:963-976, also *Journal WPCF*, 28:8:963-976.

Dembitz, A.E. (February 1978). "Belt Filter Presses: A New Solution to Dewatering." *Water and Wastes Engineering*, 15:2:36-42.

Dentel, S.K., Abu-Orf, M.M., and Griskowitz, N.J. (1993). *Guidance Manual for Polymer Selection in Wastewater Treatment Plants*, Water Environment Research Foundation.

Dentel, S.K. and K.M. Wehnes. (1988). *Monitoring Sludge Dewaterability by Streaming Detection.* Paper presented at Can. Soc. Civ. Eng. – ASCE Joint Natl Conf. Environmental Eng., Montreal, Que., Can. 254.

Emery, B.P. (1994). Predicting Belt Filter Press Performance Using Laboratory Techniques. Masters Thesis, Dept. of Civil Engineering, University of Illinois at Urbana-Champaign.

Gale, R. S. (March 4, 1967). "Filtration Theory with Special Reference to Sewage Sludges." *Water Pollution Control*, 66:622-632.

Gale, R.S. and R.C. Baskerville. (1967). "Capillary suction methods for determination of the filtration properties of a solid/liquid suspension." *Chemistry and Industry*, 9, 355-356.

Galla, C. A., D.L. Freedman, B.F. Severin, and B.Y. Kim. (October 1996). "Laboratory Prediction of Belt Filter Press Dewatering Dynamics," *Proceeding of the Water Environment Federation 69th Annual Conference*, Residual and Biosolids Management Symposium, Dallas, TX.

Galla, C. A. (1996). Laboratory Prediction of Belt Filter Press Dewatering Dynamics. Masters Thesis, Dept. of Civil Engineering, University of Illinois at Urbana-Champaign.

Galla, C.A. (1997). Personal communication concerning belt filter press and Crown Press information.

Greenburg, A., L. Clesceri, and A. Eaton. (1992). *Standard Methods for the examination of water and wastewater*. 18th Edition, American Public Health Association, Washington, D.C.

Halde, R.E. (1980). "Filterbelt pressing of sludge – a laboratory simulation." *Journal WPCF*, 52:2:310-316.

Haworth, P.J. (October 1973). "The Filterbelt Press." *Effluent and Water Treatment Journal*, 13:617-625.

Higgins, M.J. (1998). Personal communication concerning cation addition to activated sludge mixed liquor.

Higgins, M.J. and J.T. Novak. (March/April 1997a). "Dewatering and settling of activated sludges: The case for using cation analysis." *Water Environment Research*, 69:2:225-232.

Higgins, M.J. and J.T. Novak. (March/April 1997b). "The effect of cations on the settling and dewatering of activated sludges: Laboratory results." *Water Environment Research*, 69:2:215-224.

Igarashi, C., K. Tanaka, T. Kitamura, K. Fugita, K. Arai, and K. Kameyama. (1993). "Development of New Polymer Dosage Control Method for Sludge Dewatering Process." *Water Science and Technology*, 28:11-12:263-272.

Johnson, G., Buchanan, G.G., and Newkirk, D.D. (November 1992). "Optimizing Belt Filter Press Dewatering a the Skinner Filtration Plant." *Journal AWWA*, 84:11:47-52.

Karr, P.R. and T.M. Keinath. (1978). "Limitations of the Specific Resistance and CST Tests for Sludge Dewatering." *Filtration and Separation*, 15:6:543-544.

Karr, P.R. and T.M. Keinath. (August 1978). "Influence of Particle Size on Sludge Dewaterability." *Journal WPCF*, 50:1911-1930.

Lecey, R.W. and K.A. Pietila. (November 1983). "Improving belt-filter-press performance." *Chemical Engineering*, 90:69-72.

Lotito, V., G. Mininni, and L. Spinosa. (1990). "Models of Sewage Sludge Conditioning." *Water Science and Technology*, 22:12:163-172.

Metcalf & Eddy, Inc. (1991). Wastewater Engineering; Treatment, Disposal, and Reuse. Third Edition. McGraw-Hill, Inc. pp. 855-877.

Neogen Corporation, Lansing, MI. (1991). Crown Press Owners Manual.

Novak, J.T. and B.E. Haugan. (1979). "Chemical conditioning of activated sludge." *J. of Environmental Engineering,* ASCE, 105:5:993-1018.

Novak, J.T., J.F. Prendeville, and J.H. Sherrard. (February 1988). "Mixing Intensity and Polymer Performance in Sludge Dewatering." *J. of Environmental Engineering*, ASCE, 114:1:190-198.

Novak, J. and W. Knocke. (June 1987). "Specific Resistance Measurements: Nonparabolic Data." G.L. Christensen and R. I. Dick, *J. Environmental Engineering Division, ASCE*, 113:3:659-663.

Novak, J., W. Knocke, W. Burgos, and P. Schuler. (1993) "Predicting the Dewatering Performance of Belt Filter Presses." *Water Science Technology*, 28:1:11-19.

Severin, B.F. (1997). Personal communication concering belt filter press and Crown Press information.

Severin, B.F. and B.H. Collins, Jr. (September 1992). "Advances in Predicting Belt Press Performance form Lab Data." *Proceeding of the Water Environment Federation 65th Annual Conference*, New Orleans, Louisiana.

Sludge Dewatering Manual of Practice No. 20 (1983). Water Pollution Control Federation, Washington, D.C., 103-127.

Tosun, I., U. Yetis, M.S. Willis, and G. G. Chase. (1993). "Specific Cake Resistance: Myth or Reality?" *Water Science and Technology*, 28:1:91-101.

USEPA (May 1986). Design Information Report on Belt Filter Presses. EPA-600/M-86/011, USEPA Water Engineering Research Laboratory, Cincinnati, OH.

USEPA (September 1987). *Design Manual, Dewatering Municipal Wastewater Sludges*. EPA/625/1-87/014, USEPA Center for Environmental Research Information, Cincinnati, OH.

Vesilind, P.A. (1994). "The role of water in sludge dewatering." *Water Environment Research*, 66:1:4-11.

Vesilind, P. A. (February 1988). "Capillary Suction Time as a Fundamental Measure of Sludge Dewaterability." *Journal WPCF*, 60:2:215-220.

Water Environment Federation (1997). *Basic Maintenance of Belt Filter Presses*. Alexandria, Va.

Water Environment Federation (1996). "Terminology Guidelines for Federation Publications." Alexandria, Va.

Water Environment Federation (1994). "POTW 1994-1995 Spending Survey." *Water Environment Technology*, 6:5:16.

Werle, C.P., J.T. Novak, W.R. Knocke, and J.H. Sherrard. (October 1984). "Mixing Intensity and Polymer Sludge Conditioning." *J. of Environmental Engineering*, ASCE, 110:5:919-934.

PREDICTING THE PERFORMANCE OF BELT FILTER PRESSES USING THE CROWN PRESS FOR LABORATORY SIMULATION

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Abstract

Belt filter presses (BFPs) are among the most commonly used devices to dewater wastewater sludge. The concept used by a BFP to achieve dewatered cake solids is relatively simple; however, replicating this performance in the laboratory in order to predict the performance of a BFP with reasonable reliability has proven to be a challenge. The Crown Press is one tool that has been shown to replicate the performance of anaerobically digested sludge on a BFP.

This study used the Crown Press to replicate and predict the performance of waste activated sludge (WAS) from the Mauldin Road wastewater treatment plant on BFPs. Several operational variables, including belt speed, belt tension, polymer type, and polymer dose, were changed on the Crown Press to predict how the changes on the BFP would affect performance. Two polymers were chosen to be tested on the BFPs at Mauldin Road based on Crown Press predictions. The first polymer performed the same as the plant's current polymer in the lab, and the second performed better (achieved higher final cake solids) than the current polymer. These predictions were borne out in the BFP tests, showing that the Crown Press predictions were accurate. The Crown Press predictions were also compared to the predictions made by the capillary suction time (CST) and specific resistance to filtration (SRF) tests. The Crown Press provided more information regarding the affect of polymer type and dose on cake solids than either CST or SRF. The Crown Press was shown to be a viable tool to assess potential changes in BFP performance with WAS when operational variables change.